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OCTOBER 1926

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33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

New York Regional Meeting, New York, N. Y., Nov. 11-12

Winter Convention, New York, N. Y., February 7-10

MEETINGS OF OTHER SOCIETIES

American Society of Civil Engineers, Philadelphia, Pa., Oct. 4-9

National Electric Light Association, Kansas Section, Manhattan, Kan., Oct. 14-16

American Electrochemical Society, Washington, D. C., Oct. 7-9

National Safety Council, Detroit, Mich., Oct. 25-29

American Welding Society Exposition, Buffalo, N. Y., Nov. 17-19

Fifth National Exposition of Power and Mechanical Engineering, Grand Central Palace, New York, N. Y., December 6-11

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

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Activities and Development of the Meetings and Papers Committee

Technical meetings of the Institute are held primarily for the purpose of bringing to the attention of the membership, current developments in the electrical art and of affording an opportunity for the interchange of views on electrical subjects. Responsibility for accomplishing these objectives rests with the Meetings and Papers Committee.

This committee is admirably fitted to keep in contact with electrical progress and to arrange for the presentation and discussion of papers. Its members include the chairmen of the sixteen technical committees and ten other members of the Institute.

The committee chairmen, through frequent meetings of their respective committees, and the remaining members through other contacts, keep in intimate touch with progress in all branches of electrical science.

The present policy with regard to conventions and the present organization of the Meetings and Papers Committee have evolved with the growth of the Institute and the accumulated experience of past years.

A system for handling papers and meetings became necessary at the very beginning of the Institute in 1884. At first these were handled by the Council, which corresponded to the present Board of Directors. In the first year one technical meeting was held and ten papers presented. In the same year the first predecessor of the present committee was appointed. It was called the Meetings and Exhibitions Committee and had three members. One technical meeting was held in 1885 and two in 1886. In the latter year it was decided to hold monthly meetings and a Committee on Monthly Meetings, consisting of three members, was appointed. The monthly meetings were started in 1887 and continued as Institute meetings until 1921.

As the Institute grew, it was found necessary in 1888 to appoint a Committee on Papers and Meetings, consisting of five members, and a separate Editing Committee, of three members. These two committees were combined in 1893, but were separated again in 1901.

The first two technical committees were appointed in 1906. In 1907 there were three technical committees and these were attached as subcommittees to the Meetings and Papers Committee, as it now was called.

In 1909 the technical committees, of which there were then six, were separated from the Meetings and Papers Committee, but in order to retain contact, their chairmen were made members of this committee. This plan is still in effect today, though the number of technical committees has increased to sixteen.

Institute meetings were held monthly, except during the summer, from 1887 until 1921. At first these were held in New York, but in later years many were held in other cities. In 1921 it was decided that there should be only three national Institute conventions and that monthly meetings should be classed as Section meetings. At that time there were forty-two Sections holding regular Section meetings.

The three national conventions were to be the Annual Convention, started in 1884; the Pacific Coast Convention, started in 1910; and the Midwinter Convention, started as such in 1913. Another national meeting, known as a Spring Convention, was initiated in 1922, but it was discontinued after 1925, principally because of the development in regional meetings.

The present yearly program of the Institute includes three national conventions and a number of regional meetings. The number of regional meetings is not fixed but depends largely on the needs and desires of the various geographical districts. Three regional meetings were held in the year 1925-1926 but it is expected that in future the number of such meetings will increase.

It is of prime importance that the programs for conventions and meetings shall treat electrical subjects from a broad viewpoint and present technical information of interest to a large institute membership which includes all branches of the profession. With a membership composed of specialists, consulting engineers, operators, executives and others it is necessary to weigh all factors if a well balanced program is to be developed.

Furthermore, the Meetings and Papers Committee, in addition to the preparation of technical programs, develops its convention programs with a view to cooperating with public officials, financiers, executives and industrial leaders, in order to advance the status of the profession.

When a convention is being planned, this committee is guided very largely by the advice and wishes of the local convention committee, which has jurisdiction over all arrangements excepting the actual selection of technical papers. The local committee has an intimate knowledge of local conditions and can best suggest those elements which will give greatest benefit to the membership in its general territory. In this regard the

ocal convention and regional-meeting committees have been most helpful and have given most valuable co-operation.

Technical papers are submitted by the authors without solicitation on the part of the committee or in case it appears desirable to present information on some specific branch of the art, are obtained as the result of solicitation or suggestion by one or more of the committee members.

Upon receipt of a paper submitted for presentation or publication, the usual course is to refer it to the technical committee or committees conversant with the subject, for the purpose of securing an opinion as to its worth.

As a result of these and other opinions a paper is either accepted, rejected or returned to the author with constructive suggestions for its revision.

Discussion of papers is almost as important as their presentation and consequently the Meetings and Papers Committee endeavors to secure intelligent discussion at all meetings by general invitation and individual request.

E. B. MEYER,
Chairman, M. and P. Committee.

Some Leaders of the A. I. E. E.

Calvert Townley, the thirty-second president of the Institute, 1919-1920, was born in Cincinnati, Ohio, Oct. 18, 1864. He prepared for college at Chickering Institute, that city, and was graduated from the Sheffield Scientific School of Yale in 1886. Returning there for a graduate course he received the degree of M. E. in 1888. A summer as a laborer helping to rebuild the burned station of the Brush Electric Light Co. of Cincinnati was followed by a seventeen year engagement with the Westinghouse Electric interests at Pittsburgh, Cincinnati, Boston and New York. Starting as road engineer, or trouble man, and later becoming designer of distribution systems he was shortly transferred to the sales department. Here, although officially free from engineering duties, his inclination led him to study the technical problems, first of electric light then of power and finally of traction. He was active in the Niagara Falls development, the equipment of the Boston subways, the New York and Brooklyn elevated systems and the New York subway. In 1904, he went with the N. Y. N. H. & H. R. R. as acting fourth vice-president, to electrify their line out of New York. About that time this railroad began acquiring utility companies, (largely trolley lines) and Mr. Townley was appointed first vice-president of the holding company to manage their utilities as a side issue. The "side issue" soon reached such magnitude that after completing electrification plans and drawing specifications, Mr. Townley asked to be relieved of construction duties and became consulting engineer for the New Haven Railroad thereafter devoting most of his time to executive management of the utilities. In 1911 he renewed his former connection with the Westinghouse Company as assistant to the president a position which he now holds. During the latter period, he has served as president of the Lackawanna & Wyoming Valley Railroad, vice-president of the Niagara, Lockport & Ontario Power Co., vice-president of the South Philadelphia Co., vice-president of the International Radio Telegraph Company and officer or director of many other companies. He has toured Europe and South America in professional capacity. During the war he superintended the erection of a turbine factory near Philadelphia, the output being very largely used for the Federal Government merchant and naval vessels.

Mr. Townley joined the A. I. E. E. as an associate in 1901 and became a Fellow in 1912. He was elected Manager in 1905, vice-president in 1908 and President in 1919. In 1923 he was chairman of the New York Section; for over five years he was chairman of the Public Policy Committee, for two chairman of the Finance Committee and, at various times, served on other Committees, including Executive, Meetings and Papers, Standards, Edison Medal and Constitution Revision. He served as vice-president and trustee of The United Engineering Society and on The Engineering Foundation Board. In 1919, Mr. Townley was chairman of the Special Committee on Development which studied the needs of the Institute and of the profession. Out of this study came the joint committee of the four Founder Societies on which he served, and then on The Engineering Council. Mr. Townley was chairman of the Organizing Conference of American Engineering Council at Washington, was elected a vice-president, later declining the presidency. He was a delegate and member of the Executive Committee of the American delegation to the World Power Conference in London in 1924 and a member of the American Industrial Mission to Mexico that same year. He has contributed many papers, mostly dealing with power and traction problems.

It is estimated that between 12,000,000 and 15,000,000 radio sets are in operation throughout the world, according to a survey recently made. Of these, the United States is believed to have nearly half, or more than 5,500,000 sets.

About 900 broadcasting stations are now operating, more than 500 being in the United States. The actual number of stations which may be operating is, of course, considerably less, owing to the number of divided-time agreements in force; this practise, however, is not common in foreign countries, as the stations are fewer and the distances between them greater. The wave bands used abroad are also much wider.

Carrier-Current Communication on Submarine Cables

Los Angeles-Catalina Island Telephone Circuits

BY H. W. HITCHCOCK[1]

Associate, A. I. E. E.

Synopsis.—*Seven telephone channels and one telegraph channel on one single-conductor deep-sea cable have been made possible by the employment of carrier current on one of the two submarine cables across Catalina channel. This is the only application of carrier telephony to deep-sea cables; the system is the shortest carrier system (26 mi.) in commercial operation; it provides more separate carrier channels (six) than has been previously attempted; and it differs in other important respects from other systems. This paper describes this carrier-current system.*

* * * * *

IN the commercial application of new developments in the electrical communication art, there are a few places which repeatedly call attention to themselves. Notable among these is Catalina Island, for it is probable that in providing telephone service across the short expanse of water which separates Catalina from the mainland, more novel improvements have been employed than at almost any other point.

The first commercial telephone communication with Catalina Island was established in 1920 when a radio system was placed in operation between Avalon and the mainland, the circuit being extended by wire to Los Angeles. This circuit was in use for several years and featured in a number of transcontinental demonstrations, including the one which was held at the opening of the service to Havana over the Key West-Havana cables.

The system is of considerable interest as it represents the only instance in which radio has been used, in this country at least, to form a portion of a toll telephone system for the general use of the public. That it was reasonably successful is demonstrated by the fact that on some days as many as 183 commercial telephone messages and a large number of telegrams were handled over it. The system also proved to be one of the first popular broadcasting stations and many letters were received from radio fans, often several hundred miles away, telling of some of the amusing conversations which were overheard.

In 1923 the radio was replaced by two single-conductor submarine cables. By that time the demands for service were too great to be met by a single circuit, while the growing interest in radio broadcasting, as well as the increasing interference from ship transmitters, rendered its continued operation very difficult and unsatisfactory. The submarine cables were of the single-conductor, deep-sea type, each providing a single-wire circuit. They are of interest for a number of reasons, chiefly, perhaps, because they represent one of the few instances of deep-sea cable manufacture in this country. From the cable hut at San Pedro, the circuit is extended to the office by means of a special lead-covered cable containing four individually shielded No. 13 B & S gage pairs for the telephone circuits and four 19-gage pairs for the telegraph circuits and other miscellaneous uses. Between the San Pedro office and Los Angeles, the circuit was composed of a No. 19 B & S gage cable phantom. At San Pedro a through-line repeater was inserted in order to secure the desired over-all equivalent between Avalon and Los Angeles. A description of these cables and their laying was given in a paper presented by the writer at the Pacific Coast Convention in 1923 and published in Volume XLII of the TRANSACTIONS.

Although the two circuits provided by the cables represented a great improvement over the previous condition as regards the quality of the service rendered and the number of messages which could be handled, it was realized that they would soon prove inadequate to handle the heavy summer business, for which eight or ten circuits would be required in a relatively short time. To provide for such a large increase by the laying of additional cables was deemed impractical, as the cost would be excessive. Furthermore, in water of this depth—3000 ft. (914 meters)—it is important that cables be laid at least a mile or two apart, so that in the event that trouble develops on one, it can be repaired without disturbing any of the others. For a total distance as short as the width of the Catalina channel—23 nautical mi. (6087 ft. or 1856 meters per nautical mi.)—such a separation between adjacent cables could not be maintained without materially increasing the length of the outer ones with a corresponding increase in their cost and in their transmission equivalents. In view of these facts, it was decided to secure as many more circuits as possible by operating carrier systems over the two cables already in use. This project was actively promoted with the result that on May 15, 1926, six carrier telephone circuits were placed in operation.

The use of carrier in the past few years has increased so rapidly that the mere addition of a new system is,

1. Transmission and Protection Engineer, Southern California Tel. and Tel. Co., Los Angeles, Calif.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

in itself, of hardly more than passing interest. In this instance, however, there are a number of factors which render the project of particular interest. It is the shortest carrier system—26 mi. (43 km.)—in commercial operation. It is the only application of carrier telephone to deep-sea cables; the system provides more separate channels (six) than has ever before been attempted, while the particular arrangement employed is different in many other important respects from anything which has been used in the past.

In order to better appreciate the reasons for adopting the system finally agreed upon, it may be of interest to review briefly the essential characteristics of carrier systems and the different types which are available. The general principles of carrier-current telephony are described at considerable length in a paper by Messrs. Colpitts and Blackwell which was published in Volume XL of the JOURNAL of the Institute.

Carrier systems may be divided into two general classes, namely, balanced or grouped, depending upon

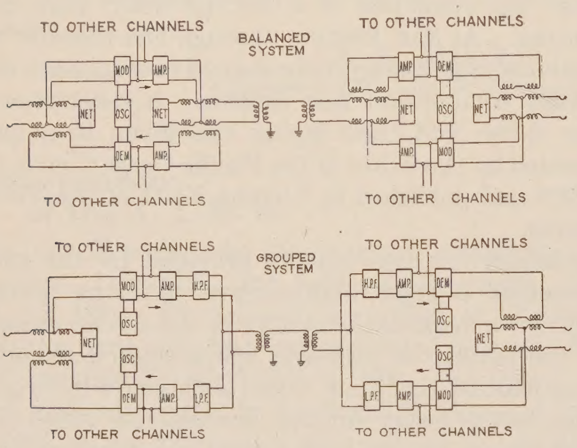

FIG. 1

the manner in which the currents in the two directions are prevented from interfering with each other at the terminals. In the balanced system this separation is accomplished by means of a three-winding transformer or hybrid coil together with a balancing artificial line such as is used with a voice-frequency repeater. In the grouped system, different carrier frequencies are used for transmission in the two directions and their separation at the terminals is effected by means of suitable band-pass filters. These two systems are shown diagrammatically in Fig. 1. The balanced system has the advantage that for each channel the same carrier frequency may be used for transmission in both directions so that there may be as many channels as there are separate carrier frequencies. On the other hand, the wire circuit must be very uniform throughout so that the impedance will be very regular over the entire carrier-frequency range, and may be simulated by an artificial line. The line must also be very stable so that the impedance balance, once having been secured, will not be disturbed. Furthermore, as transmission with the same carrier takes place in the two directions, the effect of the cross-talk between systems of the same type is very severe, so that it is usually impractical to operate two of these over wires which are in close proximity for any considerable distance. The grouped system has the advantage that a balancing line is not required and hence small circuit irregularities are relatively unimportant. Furthermore, the effect of

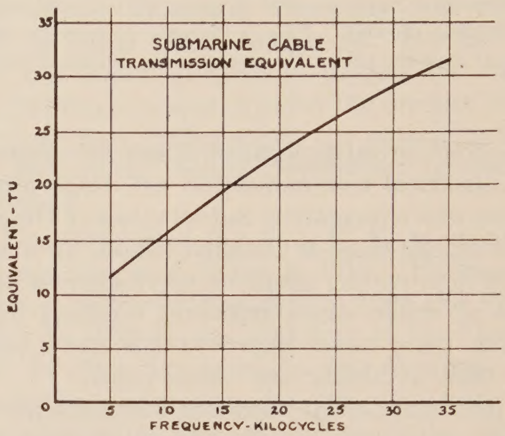

FIG. 2

cross-talk is much less severe, so that a number of systems may often be operated over adjacent circuits. One disadvantage is that two carrier frequencies are required for each channel so that fewer circuits can be secured with one system.

Carrier systems may also be divided into two classes depending upon the manner in which the carrier current is provided at the receiving end. In the carrier trans-

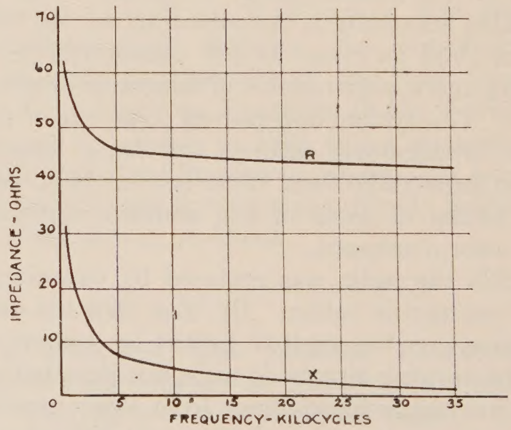

FIG. 3

mission system, the carrier current is supplied by the oscillator at the sending end and is transmitted over the circuit along with one or both of the side bands. In the carrier suppression system, the carrier current itself is not transmitted but is introduced into the receiving equipment from a local source. This latter system is proving to be superior for general carrier purposes because of the advantages which accrue from relieving

the line and apparatus from the load of the carrier current.

Turning now to the electrical characteristics of the cables, we find that each one provides a circuit having a transmission equivalent which increases throughout the carrier range but is moderate in magnitude. The impedance, as is to be expected with a uniform, non-loaded cable, is very smooth, and since there is no opportunity for any change in the cable constants, the impedance has practically no variation. The transmission equivalent and the impedance of one of the cables are shown in Figs. 2 and 3 respectively. The cross-talk between the cables is small enough to be entirely negligible, regardless of the type of carrier systems employed.

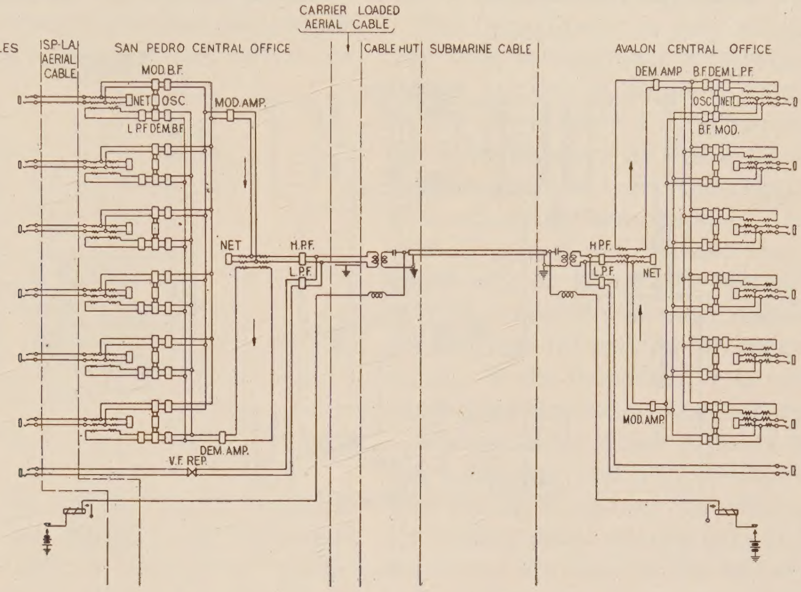

FIG. 4

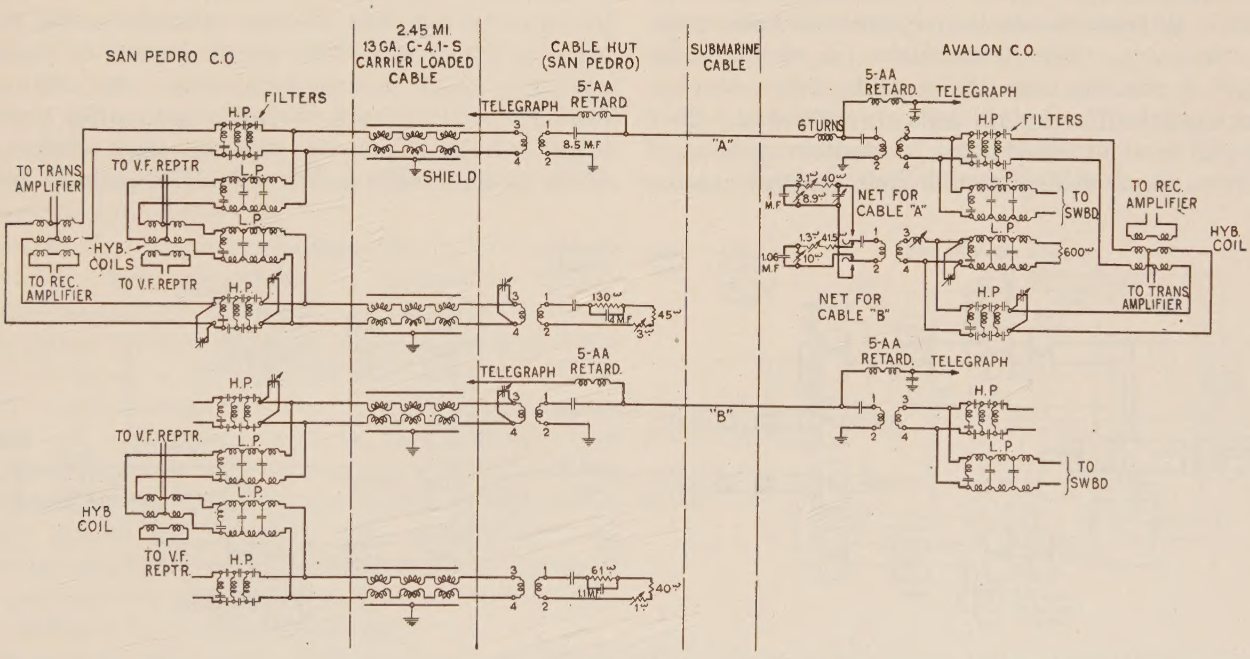

FIG. 5

In view of all the conditions outlined, a balanced system of the carrier suppression type was decided upon. Such a system provides the maximum number of channels per cable, while the usual difficulties of impedance balance and inter-system cross-talk are largely absent due to the unusual characteristics of the cables. The adoption of such a system also made possible the employment of standard units of equipment of the most recent design. The general nature of the system and the arrangement of the component parts is shown diagrammatically in Fig. 4. Fig. 5 is a simplified circuit diagram showing the filters for separating the various circuits at the terminals, together with the balancing arrangement. In Fig. 6 are shown the essential parts of one channel together with the amplifiers

and the hybrid coil which are common to all the channels. For convenience, some of the battery and auxiliary circuits have been omitted in the figure.

At the time the system was under development, it was uncertain that balanced operation of all channels over a single cable would be practicable, so that an alternative arrangement involving substantial four-wire operation over the two cables was provided for. With this arrangement, which is shown diagrammatically in Fig. 7, all transmission in one direction takes place over one cable, while transmission in the opposite direction is effected over the second cable. No balancing equipment or hybrid coils are employed. Such an arrangement would increase the system stability, if such were required, but would limit the total carrier capacity of the two cables to six channels. In the event of the failure of one cable, operation with such a system would be impossible, and it would be necessary, at that time, to revert to the two-wire arrangement as described above, with a possible reduction in the over-all gain or a reduction in the number of operating channels.

As may be seen from Fig. 4, a carrier-equipped cable provides a d-c. telegraph circuit, and one voice-frequency, and six carrier-frequency telephone channels. The separation of the various channels is effected by means of electrical filters. Fig. 8 shows the band of frequencies employed for each channel. For the d-c. telegraph this separation is effected at the terminals of the cable as is shown in Fig. 5. The telegraph circuit requires a continuous d-c. path, whereas the telephone channels require the insertion of an inequality ratio insulating transformer at the ends of the cable in order to properly join the 43-ohm grounded cable circuit with the 600-ohm metallic circuit formed by the office equipment and intermediate cable. As this transformer must pass both the voice and carrier channels, it has been designed so as to have a high efficiency for all frequencies between 250 and 30,000 cycles. Separation of the voice-frequency circuit from the carrier system is performed by means of the usual high and low pass filters which are located at the central offices. These filters both have a cut-off frequency of 3000 cycles, the low pass transmitting all frequencies below this value and the high pass transmitting all above it. In the carrier system the transmitting and receiving currents are separated from each other by a hybrid

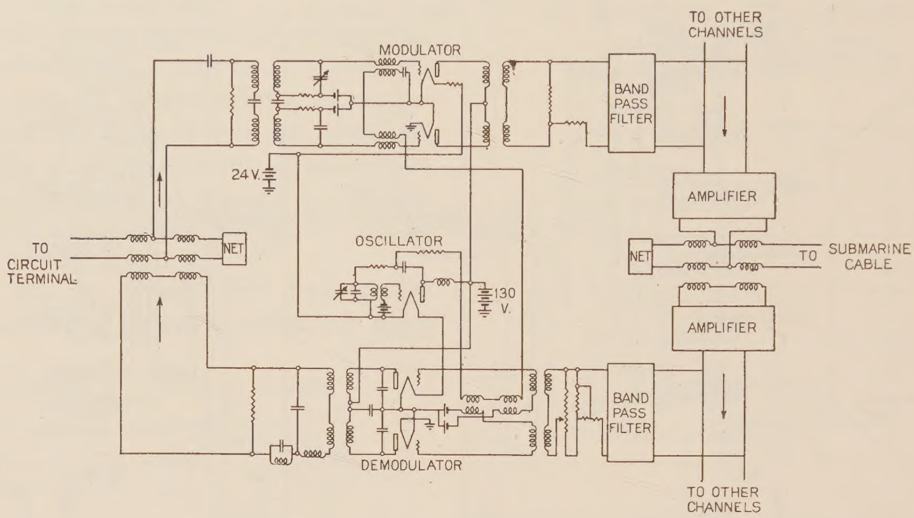

FIG. 6

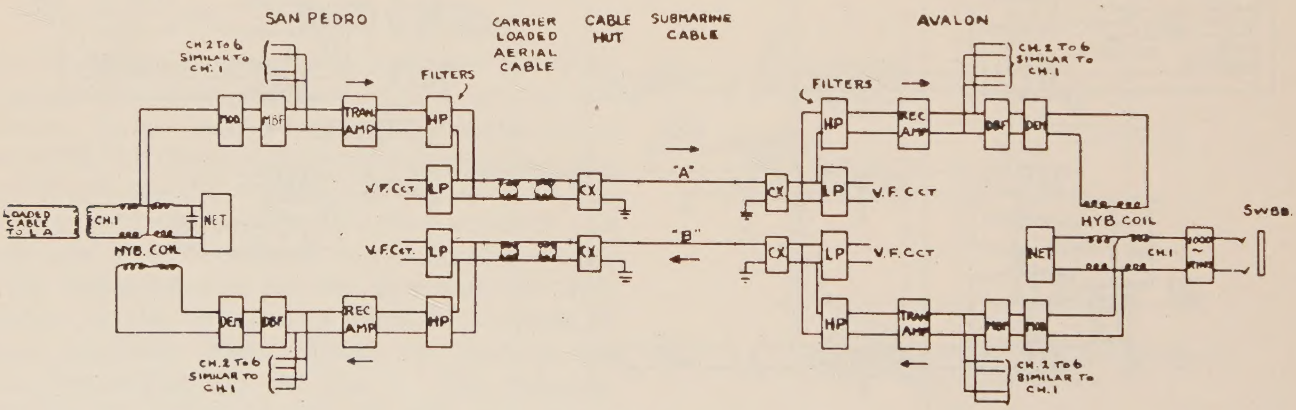

FIG. 7

coil and balancing network. Between the output of the six modulators and the common transmitting amplifier, individual band-pass filters are located. Each one of these filters is designed to transmit one of the side bands produced by the modulator associated with it and to suppress all other frequencies. The six receiving currents are separated in a similar manner. Each filter allows current of the proper frequency to pass to the corresponding demodulator and excludes all others. Each demodulator is also provided with a low

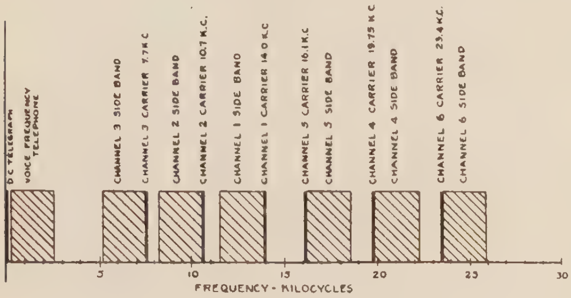

FIG. 8

pass filter which allows the passage of the resulting voice-frequency current but excludes all incidental higher frequencies which might be present and render the circuit noisy. The input of each modulator and the output of the corresponding demodulator are finally joined by means of a voice-frequency hybrid coil and extended to the circuit terminal as a two-wire circuit. At the San Pedro end, each two-wire circuit is extended to Los Angeles over a loaded cable circuit. Phantoms are employed for this purpose as they have a higher cut-off frequency than have the side circuits, with a correspondingly better quality.

Concerning the carrier system itself, the two ends are practically identical while the general equipment arrangement for an individual channel is the same in all cases except for the frequency of the band-pass filter. For this reason, a consideration of one channel is sufficient. Each channel is composed of a voice-frequency hybrid coil, a modulator with its band-pass filter, an oscillator, and a demodulator, together with its associated filters. In addition, there is, at each end, a carrier hybrid coil together with transmitting and receiving amplifiers which are common to all channels. The arrangement of this equipment is shown schematically in Fig. 6, as previously indicated.

The modulator the input of which is connected to the center taps of the hybrid coil line windings consists of two vacuum tubes arranged for push-pull operation. The carrier current which is supplied by the oscillator is applied to the two grids by means of a transformer. Such a circuit generates the two side bands but suppresses the carrier. In order that this suppression may be as complete as possible, the small condenser associated with the grid of one of the tubes is made variable and is adjusted until the carrier current in the modulator output is reduced to a minimum. The band-pass filter transmits one of the side bands and suppresses the other, as well as all miscellaneous resultant currents of a higher order which are produced by the modulator. It also prevents the output currents of the other channels from entering the modulator circuit as this would cause a reduction in their efficiency and give rise to undesirable frequencies.

The demodulator is very similar to the modulator. The tube arrangement is substantially the same and carrier current is supplied from the one oscillator. In the demodulator a complete suppression of the carrier is unnecessary as this is accomplished by the low pass output filter. For this reason, the small balancing grid condensers are omitted. In order to adjust the over-all gain of the channel, the demodulator is provided with an adjustable potentiometer graduated in two transmission unit steps, and in addition, fixed pads are provided for making further gain adjustments. The output of the demodulator is connected to the series winding of the voice-frequency hybrid coil.

The oscillator which supplies the carrier current to the modulator and demodulator is of the usual type. The tuning condenser includes a small variable unit for making small adjustments in frequency. Separate oscillators are used at the two ends for each channel, and as these are in no way connected together, it is occasionally necessary to make slight adjustments in order to keep the frequencies at the two ends substantially equal. The oscillators are very stable, however, and such adjustments are seldom required.

The individual channel filters are all of the band-pass type as previously indicated and have a free transmission range of approximately 2500 cycles. Outside

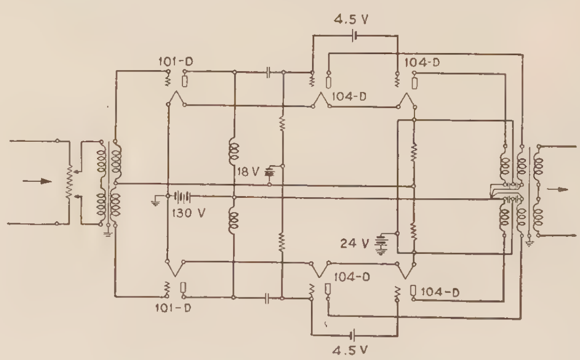

FIG. 9

this free range they have a high impedance so as not to act as a shunt for the other channels. They are all of substantially the same construction, although the constants of the component parts necessarily vary as the filters for the different channels transmit different frequencies.

The transmitting and receiving amplifiers, which are practically identical, are shown schematically in Fig. 9. They consist of two push-pull stages connected in tandem. Each half of the second or output stage con-

sists of two parallel tubes of high output capacity. In this way a comparatively high gain and a large energy output may be secured without overloading. This is very important as these amplifiers are common to all six channels and any tendency to overload would produce objectionable distortion and inter-channel modulation. In order to adjust the over-all gain for the entire system, each amplifier is provided with an input potentiometer.

As has been previously indicated, the transmitting and receiving circuits are joined to the cable by means of a hybrid coil. Probably the most difficult problem encountered in the installation of this system was the securing of an adequate balance. The difficulty of doing this may be better appreciated when it is realized that this balance must cover all frequencies from 3000 to 30,000 cycles, and must have a value of from 30 to 45 T. U., the higher value which represents an impedance unbalance of approximately one per cent being required at the upper frequency. In order to secure

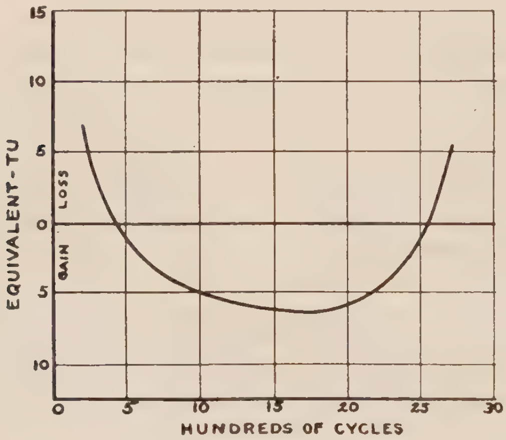

Fig. 10

such a balance, every part of the line circuit was matched by a similar part in the network circuit. All filters and transformers on the line side of the hybrid coil were duplicated in the network, and on the San Pedro side a 13-gage carrier-loaded cable pair was included in the network circuit between the office and the cable hut, and the inequality ratio transformer and basic network simulating the cable were located at the latter point. In addition to providing a balance within the carrier range, it was necessary at the San Pedro end for the network circuit to balance the cable within the voice-frequency range as a through-line repeater is employed on the voice-frequency circuit. Not only was it necessary to duplicate all parts in the line and network circuits but in addition they were carefully selected and paired so that the two parts associated would have, as nearly as possible, the same electrical characteristics. All wire pairs within the office which appeared in the carrier frequency circuits were individually shielded by means of a grounded metallic covering. The 13-gage carrier-loaded pairs in the cable joining the hut and the office were also individually shielded by means of a lead foil wrapping. This was done in order to preserve the balance and prevent cross-talk with another system which may be placed on the second cable at some future time.

Although extreme care was exercised in making the refinements described, the balance was still lower than was desired so that small variable auxiliary impedances were inserted at suitably chosen points in the line and network circuits. By the adjustment of these elements, it was found that the balance could be raised to any desired value for any particular channel, but that in so doing, the balance on some of the others would be impaired. By careful adjustment, however, it was possible to secure a balance for all channels within the range previously mentioned. As the transmission equivalent of the cable increases with the frequency, the over-all channel gains must be increased in the same manner in order that all circuits may have the same over-all equivalent. The networks were therefore arranged so that the higher frequencies would have the better balance, as in that way the margin of balance over gain could be made substantially the same for all channels. Since this margin should not be allowed to fall below a fairly definite minimum if the circuit is to have the desired stability, it is evident that the balance which may be secured determines the over-all gain which is possible. In this case the circuit equivalent for all channels between Los Angeles and Avalon was set at five T. U. As the loaded cable between Los Angeles and San Pedro is approximately nine T. U., it may be seen that the carrier system actually introduces a gain and performs the function of a repeater besides increasing the number of circuits. Fig. 10 gives a frequency characteristic of one of the channels which is typical of all of them. Balancing equipment has been provided for both cables as is shown in Fig. 5. With this arrangement, the carrier system may be operated over either cable. The transfer from one cable to the other is so simple that it can be made with practically no traffic interruption.

Signaling over the carrier channels is effected by means of 1000-cycle ringers which are connected to the circuits at the two terminals. As the ringing current is within the voice range, it is transmitted over the regular carrier channel so that no additional signaling equipment is necessary.

In order to insure satisfactory operation, all necessary testing facilities are included. Meters and keys are provided for measuring the voltages of the plate, grid and filament batteries as well as the plate and filament currents of all tubes. Individual rheostats are inserted in all filament circuits for making any adjustments that may be necessary. Alarms are provided to indicate any abnormal condition which might develop on any tube. Thermocouples and artificial lines have been conveniently arranged for checking the efficiency of all units such as the modulators and demodulators.

Jacks are located at suitable points so that any changes which may be necessary can be quickly made.

The general appearance of the carrier system may be seen from Figs. 11 and 12 which show the equipment at

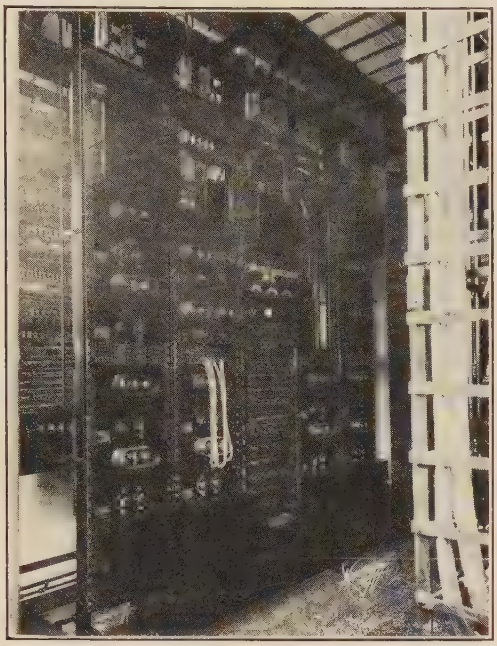

Fig. 11

San Pedro and Avalon respectively. Fig. 13 is an interior view of the San Pedro cable hut showing the cable terminals, together with the insulating trans-

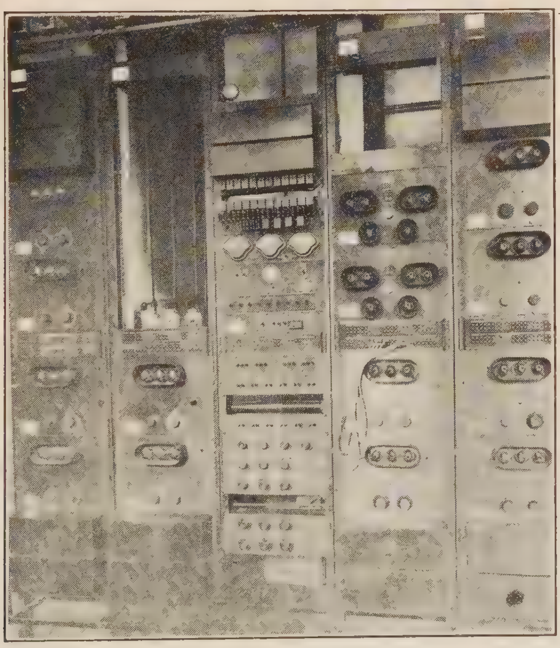

Fig. 12

formers, telegraph composite sets, and basis networks. Referring to the central office equipment, the first bay contains the equipment for two complete channels. At the top are the terminal strips for making all connections with the equipment below. On the next two small panels are mounted the hybrid coils and the other miscellaneous apparatus associated with the voice-frequency ends of the two channels. Below these are the modulator and demodulator band filters which are covered with dust proof cases. Next comes the modulator and demodulator panels for one channel. Below the two jack strips is mounted similar equipment for a second channel but arranged in reverse order. In the upper half of the second bay is located a small panel mounting the carrier hybrid coil and associated equipment. Below this appear the transmitting and receiving amplifiers. The lower half of the bay is similar to the lower half of the first one. In the third bay is mounted all the battery supply and testing apparatus. The first two units contain the battery retard coils. Below these are the alarm relays and auxiliary resistances. Next come the meters for measuring the tube currents and voltages, and below these are the

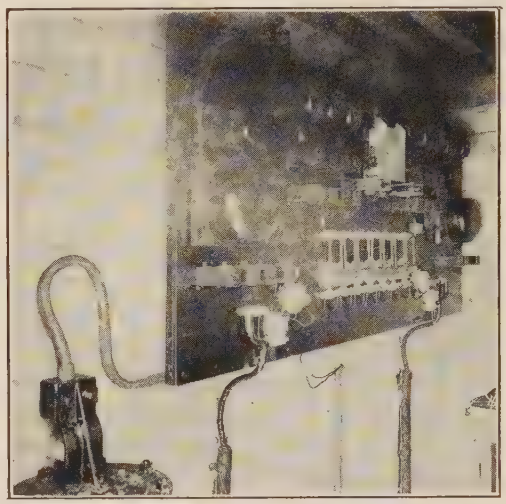

Fig. 13

thermocouples and artificial lines for making high frequency measurements. Below the jack strip are the keys for opening and closing the individual filament circuits used for measuring the plate and filament currents. Alarm lamps are also associated with each of the filament circuits. The fourth bay is similar to the second except that the upper half is vacant. As may be seen from the photographs, the amplifiers appear on the second bay at San Pedro and on the fourth at Avalon. The fifth bay is an exact duplicate of the first.

The new system has now been in successful operation for the past five months. In the light of its performance thus far, we feel assured that when more circuits are required a second system of six channels can be added to the second cable, thus providing a total of fourteen telephones and two telegraph circuits over the two single-conductor cables. Such a circuit group, we believe, will meet the traffic requirements for quite a number of years.

Temperature of a Contact
and Related Current-Interruption Problems

BY J. SLEPIAN[1]
Associate, A. I. E. E.

Synopsis.—*A formula is derived for the temperature rise of the last contact point of a pair of separating electrodes. The relation of this to arcing at a switch, brush drop, and commutation, is discussed. Experiments on the interruption of current by a switch in vacuum are described.*

* * * * *

Low-Voltage Sparking at a Contact. It is a matter of common knowledge that when a circuit carrying current is opened at a pair of contacts, a flash of light which may be a spark or an arc results, even though the voltage of the circuit may be quite low. For example, if the blade of a knife is drawn across the terminals of a dry cell, a shower of sparks is thrown off, even though the cell gives only 1½ volts. This phenomenon calls for explanation, since to start or maintain a discharge in gases or metal vapors in general calls for certain minimum voltages.

To start a discharge in a gas between separated electrodes requires in general several hundred volts, and to maintain an arc discharge, except under very special conditions, fifteen volts or more are required. How is it that the short-circuited, 1.5-volt battery gives such brilliant sparks?

Temperature at the Last Contact. An analysis of the thermal conditions at the last point of contact of a pair of separating electrodes suggests an answer to this question which has been raised. As the electrodes separate, the area of contact becomes smaller and smaller, so that the ohmic resistance through the electrode material up to the contact area becomes larger and larger. When the contact area reduces to a geometric point, this ohmic resistance becomes infinite. Hence, if a discharge does not start, all the voltage of the circuit must ultimately concentrate on this last contact. With metal electrodes, this means that there is an enormous concentration of current and power at the last contact so that a very high temperature is attained.

In the appendix, an approximate formula is derived for the temperature rise of a small contact between large electrodes when E volts are applied to it. It is

$$T = \frac{E^2}{33.5\, k\, \rho} \tag{1}$$

where ρ is the electrical resistivity (ohms/cm.^{3}) and k the thermal conductivity (calories/cm.^{2}/deg. cent/cm.). Table I shows the temperatures for different electrode materials and voltages.

Thermionic Emission and Thermal Ionization. The very high temperatures indicated in Table I for metal electrodes permit a ready explanation of the discharge obtained at separating electrodes, for there are two ways known by which the minute gap between the electrodes will be made conductive by a sufficiently

TABLE I
TEMPERATURE RISE OF CONTACT

Electrodes	1–Volt	10-Volt	100–Volt
Metal $\rho = 10^{-5}$ $k = 1.0$	3000 deg.	3×10^5 deg.	3×10^7 deg.
Carbon brush $\rho = 0.01$ $k = 0.05$	60 "	6000 "	6×10^5 "
Autovalve arrester disc. $\rho = 100$ $k = 0.02$	0.015 "	1.5 "	150 "

high temperature. One is by thermionic emission from the electrode which is cathode. It is well known that at sufficiently elevated temperatures, current may be

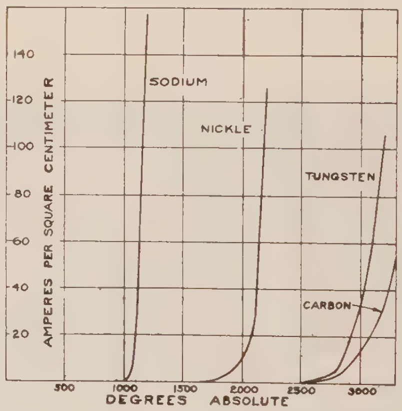

Fig. 1—Thermionic Currents from Metals

passed from a cathode into space by means of emitted electrons. Fig. 1 gives the relation between thermionic current density and temperature for a few metals.

Another way in which a high temperature may make the space between the electrodes conductive is by thermal ionization of the gas or vapor there. Saha[2] showed that at sufficiently high temperature, gases will undergo a spontaneous ionization which will render them conductive. Fig. 2 gives for various gases the current density at the cathode as a function of temperature calculated from Saha's equation and the theory of

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Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

2. *Phil. Mag.*, **40, p. 472, (1920).**

Langmuir[3]. Since the vapor given off by a metal has the temperature of the metal, if the last contact is sufficiently hot, the vapor which it gives off will be highly conductive.

Examination of Figs. 1 and 2 shows that, to obtain high current densities, either by thermionic emission or by thermal ionization, temperatures in excess of the boiling points of the electrodes will be required. At first sight this presents a difficulty, as it may be thought that the rapid vaporization of the electrodes with the accompanying absorption of latent heat would prevent further rise of temperature of the contact. However, at any particular temperature, the rate of vaporization from a surface is finite, whereas the energy input density into the contact becomes infinite as the contact area approaches zero. Hence the vaporization cannot limit the temperature of the last contact point. The temperature of the last contact will be prevented from reaching the values of Table I only by current being diverted from it into the surrounding space or vapor.

Opening of Switch Carrying Current. The preceding

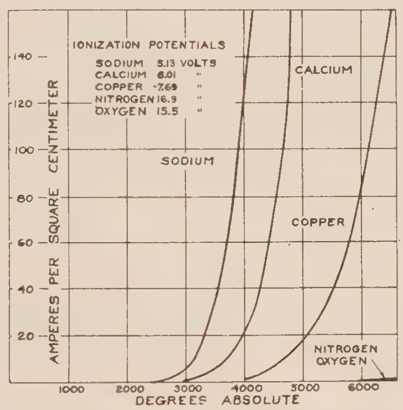

Fig. 2—Thermal Ionization Current Densities

considerations show that the opening of a switch with metal or other low-resistivity electrodes will always be accompanied by a discharge if there are more than a few volts in the circuit, and this will be true regardless of the medium in which the switch is placed, whether it be air, oil, or even high vacuum. If the circuit voltage is more than 15 or 20 volts, this discharge will change over into an arc discharge when the contacts become completely separated. This arc will be stable with very small electrode separation, but may become unstable when the electrode separation is increased.

As Table I shows, it is possible to increase the voltage necessary to start an arc at a switch contact by raising the electrical resistivity of the electrode material. This was mentioned in a paper on the "Autovalve Arrester"[4] and Fig. 3 is reproduced therefrom. The parabolic form of this curve is predicted by equation (1).

Switch in High Vacuum. Before these considerations were appreciated, the author believed that in a sufficiently high vacuum, arcless operation of a switch could be obtained even with relatively high voltage. Accordingly some experiments were carried out under his direction by Mr. W. J. Cahill. The tube was constructed as shown in Fig. 4. The contacts were held together by one of the supporting arms being a steel spring, and they were pulled apart by the action of the coil shown upon the iron armature

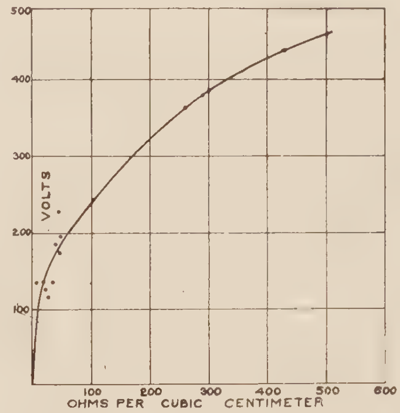

Fig. 3—Voltage to Draw an Arc by Contact

connected to the movable contact. The contacts could be changed, being held in place by a screw and nut.

The following combinations of electrodes were tried: Cu-Cu; Fe-Fe; Ni-Ni; Ni-Fe; Ni-Cu; C-Fe; C-Ni; C-Cu. The contact was placed in a 110-volt, d-c. circuit, with

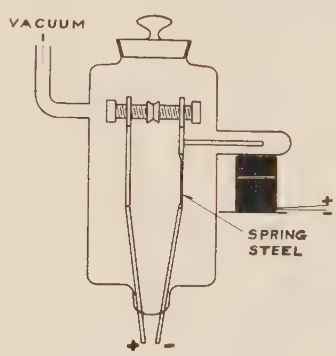

Fig. 4—Vacuum Switch

current controlled by a rheostat. In no case was inductance purposely introduced.

The tests showed that even with a vacuum of 0.001 mm., a luminous flash was produced with currents as low as one or two amperes. As the current was increased in strength, the flash became more intense, and appeared to persist for a longer time. The contacts quickly roughened under repeated service, and usually failed at from 40 to 50 amperes by welding together on closing. The best results were obtained with the carbon nickel combination, which could be made to work at 45 amperes at the rate of five or six times a minute.

The reason for the disappointing results is quite evident. It was impossible under the conditions of the

3. G. E. *Review*, 27, p. 449, (1924).
4. A. I. E. E. Journal, January, 1926, p. 3.

test to avoid a high temperature at the last contact. This meant volatilization of the electrode, and momentarily an arc carried in the electrode vapor. This arc would be very rapidly extinguished by the quick condensation of the electrode vapor, so that the principal obstacle to the practical application of the vacuum break was the consumption and roughening of the electrodes, and the difficulty of getting enough pressure upon the contacts to overcome the effect of this roughening.

Sparkless Commutation. The commutation of current in the ordinary d-c. generator and motor is perhaps the best example of continual opening and closing of heavy current circuits without arcing. It is interesting to consider present practise in the way of voltages and brush resistivities in the light of Table I. The voltage per bar on d-c. machines is usually from 15 to 20 volts, and in the commutating zone this is reduced by means of interpoles to less than a volt or two. Carbon brushes for d-c. service have resistivities from 0.001 to 0.01 ohm per cm.[3] Looking at the second example in Table I, we see that one volt gives a temperature rise of 60 deg., whereas 10 volts gives a prohibitively large temperature rise. Thus it appears that the limits for successful commutation are determined by the temperature of the last contact of brush and segment.

Contact Drop of Brushes. In the usual theories of commutation, the property of brushes considered is the contact drop of potential. That is, it is found experimentally that when less than a certain (usually rather erratically varying) voltage is applied between brush and commutator or slip ring, only a small current flows,

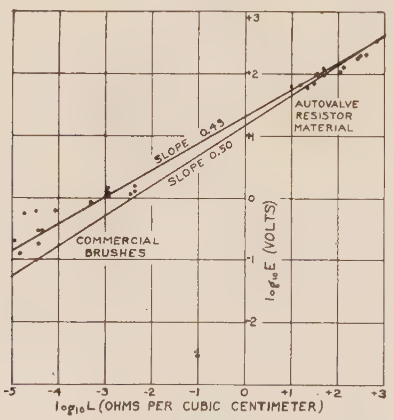

Fig. 5—Brush Drop and Resistivity

whereas if this voltage is exceeded very large current flows. The preceding paragraph suggests that this property of contact drop has a thermal origin, and that the contact drop is that voltage at which the relatively few points of intimate contact reach such high temperatures that conductivity is given to the space around them.

If this were so, then by formula (1), for brushes of the same thermal conductivity, there should be proportionality between the square of the contact drop and the brush resistivity. Mr. C. F. Wagner has collected data on commercial brushes, and also data on contact drop of high resistivity material such as is used in autovalve disks. These he plotted on double log paper as is shown in Fig. 5. The best straight line which can be drawn through these points has a slope of 0.43, indicating a quadratic law and supporting a thermal theory of contact drop.

Appendix

Calculation of Temperature Rise of a Contact

Let the line $O\,O$, Fig. 6, indicate a section of the face of one electrode, and let $A\,A$ be a diameter of

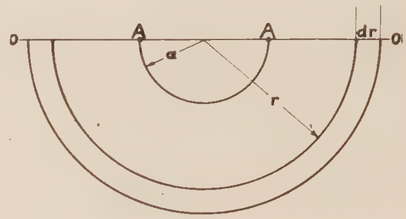

Fig. 6

contact spot, assumed circular. Then one-half of the ohmic drop across the contact will occur between the circle $A\,A$ and the rest of the electrode. It will make the calculation easier and introduce only a small error if we assume that the voltage $\frac{E}{2}$ is applied not at the circle $A\,A$, but between a hemisphere constructed on $A\,A$, and the rest of the electrode. Let the radius of this sphere be a.

The potential at the surface of this sphere is $\frac{E}{2}$, and within the electrode at a distance r from the center of this sphere the potential will be

$$V = \frac{E}{2}\,\frac{a}{r} \tag{2}$$

The potential gradient will be

$$-\frac{\partial V}{\partial r} = \frac{E}{2}\,\frac{a}{r^2} \tag{3}$$

The Joulian heat will therefore be

$$\frac{1}{4.19}\,\frac{1}{\rho}\left(\frac{\partial V}{\partial r}\right)^2 = 0.059\,\frac{E^2}{\rho}\,\frac{a^2}{r^4}$$

$$\text{calories/cm.}^3\text{/sec.} \tag{4}$$

The heat evolved in a hemispherical shell of radius r and thickness $d\,r$ will be

$$2\,\pi\,r^2\,d\,r \times 0.059\,\frac{E^2}{\rho}\,\frac{a^2}{r^4} = 2\,\pi\,0.059\,\frac{E^2}{\rho}\,\frac{a^2}{r^2}\,d\,r$$

$$\text{calories/sec.} \tag{5}$$

Letting k be the heat conductivity of the material and T the temperature at any point, the heat flowing into the shell from the inner surface will be per sec.,

$$- k \times 2 \pi r^2 \left(\frac{\partial T}{\partial r} \right)_{r=r} \quad \text{calories/sec.} \tag{6}$$

The heat flowing out of the shell from the outer surface will be

$$- k \, 2 \pi (r + d r)^2 \left(\frac{\partial T}{\partial r} \right)_{r=r+dr} \tag{7}$$

In the steady state, (5) = (7) − (6), hence

$$k \, 2 \pi r^2 \left(\frac{\partial T}{\partial r} \right)_{r=r} - k \, 2 \pi (r + d r)^2 \left(\frac{\partial T}{\partial r} \right)_{r+dr}$$

$$= 0.375 \, E^2 \frac{a^2}{r^2} d r \tag{8}$$

Hence, dividing by $d r$ and passing to limit,

$$- 2 \pi k \frac{\partial}{\partial r} \left(r^2 \frac{\partial T}{\partial r} \right) = 2 \pi \times 0.059 \frac{E^2}{\rho} \frac{a^2}{r^2} \tag{9}$$

Integrating with the boundary condition $T = 0$ and $\frac{\partial T}{\partial r} = 0$ when $r = \infty$,

$$T = \frac{E^2}{33.5 \, k \, \rho} \frac{a^2}{r^2} \tag{10}$$

Letting $r = a$,

$$T = \frac{E^2}{33.5 \, k \, \rho} \tag{11}$$

RELATIVITY IN OBLIQUE COORDINATES

During the past three years Professor Vladimir Karapetoff has given talks on "Straight-Line Relativity in Oblique Coordinates" before several Institute Sections, as well as at some conventions of other societies, and has demonstrated his "blue and red" mechanical model of Einstein's fundamental relations. Institute members and readers of the JOURNAL will be interested to know that an article by Professor Karapetoff, containing a detailed elementary theory of restricted relativity in his oblique coordinates and a description of the model, has appeared in the August issue of the *Journal of the Optical Society of America.* Professor F. K. Richtmyer, Cornell University, Ithaca, N. Y., is the Business Manager of the *Journal*; the price of single issues, as long as they last, is 60 cents.

ELECTRICITY TO KEEP TRAINS SAFE

Making 7770 miles of railway in the United States safe against train collisions is no trivial task The accomplishment, as announced by the Interstate Commerce Commission July 28, marks the progress of the first quarter century of automatic train control in this country. This announcement registers the fact that after many years of heartbreaking experiment with all sorts of strange devices for stopping trains from running into danger, electricity has proved the only agency whereby this can do it. Hence the Commission has now given approval for train control schemes protecting 7770 track miles. How fast the Commission may order the rest of the country's mileage under automatic train control remains to be seen.

Most of the automatic control and stop devices in service consist of a magnet, about rail high, beside the track at the point where it enters each signal block. Suspended from each locomotive is another type of magnet. When they pass, a flash of electric current opens a relay which actuates an air mechanism in the engineer's cab so as to set the brakes at once and bring the train to a stop.

It is provided that the engineer can forestall this brake setting by touching a button or small lever as his engine passes over each of the track magnets. He must, therefore, be alert at all times or his train will be taken out of his hands and brought to a standstill whether or not there is immediate danger ahead. This is electricity's guarantee that train operation in the future will be safer.

In 1914 the first permanent installation of a device to stop trains automatically was made on the Chicago & Eastern Illinois which runs south out of Chicago. Since then a vast amount of study and test has produced four or five general types which are now in use. Some exercise only intermittent control over trains operating only at given points. Others are continuous. Some merely apply brakes once, so as to bring a train to a stop with what is known as a "service" or ordinary application of air. Others begin by slowing down a train at one point, setting the brakes up tighter if the train passes another point and finally clamping down the shoes for an "emergency" stop.

Nearly all of them operate in connection with the block signal system. Since electric block signals, after long years of use, have proved that they fail only once in 40 million operations, the attached train control device is not going to suffer much instability by reason of signal system failure. But none of the devices that have been approved are considered beyond the possibility of improvement. Thus the 7770 miles of track and the 3700 engines equipped with the new appliances are considered a vast experimental laboratory to prevent many wrecks and save many lives while loading up to a closer approach to perfection in automatic train control.

Measurement of Transients by the Lichtenberg Figures

BY K. B. McEACHRON*

Member, A. I. E. E.

Synopsis.—The paper gives the results of a comprehensive study of the effect of transients on the size and appearance of Lichtenberg figures. Sixteen different rates of voltage rise were used, varying from about 20 minutes to 0.1 microsecond to reach a crest value of 25 kv. Results were obtained with transients the crest voltages of which ranged from 5 to 25 kv. The steeper wave fronts were checked with the Dufour cathode-ray oscillograph.

Calibration curves are given, showing that the positive figures are not much affected by changes in wave front, while the negative figures vary considerably with changes in wave front, especially at the lower voltages.

The positive figures are divided into three types according to their appearance which is found to depend on the rate of voltage rise. It is concluded that for most conditions the size of the positive figures will give a determination of the crest voltage of the applied transient to within approximately 25 per cent.

UNTIL the cathode-ray oscillograph was applied to the measurement of transient phenomena, engineers were unable to determine accurately by experiment the form of a transient voltage or current, the wave front of which occupied only a few millionths of a second of time. Such transients may occur on transmission or distribution circuits during periods of disturbance,—as, for instance, during a lightning storm,—and may cause considerable damage to unprotected apparatus.

Although the cathode-ray oscillograph can be arranged to show the volt-time, ampere-time or volt-ampere relations, yet there is need of a device which may be used to record these disturbances with fair accuracy at the same time involving a small amount of equipment so that a large number of them can be spread over the systems of the country at a comparatively small cost.

Lichtenberg Figures

If a sheet of insulating material, such as hard rubber or glass, is placed on a metal sheet and an electrode of any shape is allowed to rest on the upper surface of the insulating material, a Lichtenberg figure will be formed by the application of voltage between the electrode and the metal sheet. The figure may be made visible by the use of chalk dust which may be applied to the insulating surface before or soon after the application of voltage. A permanent photographic record of the figures can be made by placing a photographic film between the electrode and the insulating plate with the emulsion side in contact with the electrode.

A large amount of work has been done with these figures in the effort to discover their exact meaning and the variables which control the figures. Among those who have experimented with them may be mentioned P. O. Pederson[1], Toepler[2], Przibram[3], and others[4], all of whom have made notable contribution to the solution of the problem of the proper understanding of the Lichtenberg figures. Peters[5] applied the Lichtenberg figures to the study of transmission line transients, and suggested means for making connections to the transmission line to determine supplementary information about the transient. In order that the surges might be recorded with respect to time, Peters made use of a moving electrode, the complete instrument being termed the klydonograph.

Cox and Legg[6] later described some of the results obtained on transmission systems by using the revolving electrode type and described an improved klydonograph which made use of a roll film. As a result of tests with the klydonograph, Cox and Legg concluded that the relation between the size of figure and crest value of the transient was not appreciably influenced by the wave front between the limits represented by a 25-cycle wave and a wave whose crest is reached in 5 microseconds.

All investigators have found that the positive and negative figures were different in appearance and that when the electrode was positive a larger figure was formed than when the electrode was negative. At times the figures are complicated by tree-like growths which have been ascribed by some to over-loading the film, but this does not always seem to be the case as they are sometimes found at lower crest voltage than that which at other times does not produce them. In the practical interpretation of the figures, it seems to be necessary to neglect these effects until their meaning is known.

Effect of Wave Front

The author is not aware of any systematic work that has been done having for its object the calibration of the figures with respect to the form of the voltage transient. Up to the present time, the figure has been regarded as not being much affected by rate of voltage application and therefore the present investigation was undertaken to determine, if possible, the relation between the size of the figure and the rate of voltage application, as well as the crest value.

A transient, such as that shown in Fig. 1, consists of three major parts; the front, and the part we may call

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*Lightning Arrester Engineering Department, General Electric Company, Pittsfield, Mass.

[1]For all references see bibliography.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

the body for want of a better name, and the tail. In the simple wave of this kind, presumably each of these parts may play a role in the production of the Lichtenberg figure. The investigation to be described in this paper is concerned altogether with the front of the wave, as the rate of voltage rise and the crest value of voltage appear to be the dominant factors in determining the characteristics and the size of the figures.

To make the work as complete as possible, tests have been carried out covering a wide range of wave fronts, the slowest being slower probably than any ever obtained in practise, while the fastest are probably as fast as any that ever occur in service, being but a few hundred feet in length. Sixteen different wave fronts at five different voltages were used and, except at the very slowest, oscillograms were taken of each voltage application. Every care was taken with the shorter waves to eliminate the effect of reflection and to keep the oscillation on the wave front to a minimum. This has been possible only through the use of the Dufour cathode-ray oscillograph[7] the voltage dividing system of which was connected directly across the electrodes producing the Lichtenberg figures, using leads only two or three feet in length.

It would have been desirable perhaps to have used

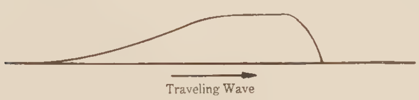


FIG. 1

a wave throughout having an initial value of $d\,e/d\,t$ kept constant up to the crest value of voltage; yet, with the steepest wave this limitation would have complicated the test seriously without adding much to the practical value thereof.

Voltage and Time Calibration

The sphere-gap was used as the primary means of determining the crest value of voltage of the transient. With the slower waves the crest potential of which was reached in times longer than 10 seconds, it was possible to check the sphere-gap against a static voltmeter and also against meters located in some of the low tension circuits. The time for the slow waves was conveniently determined with a stop watch.

Within its range, the electromagnetic oscillograph record gave the time calibration of the transient, the time being based on a 60-cycle wave recorded on the same film. The transients above the range of the electromagnetic oscillograph were recorded with the Dufour cathode-ray oscillograph with time scale calibrated by the use of a wave meter. With the type of circuit used, the wave front could be calculated quite accurately and, except for the oscillations which in most cases were successfully removed, the oscillograms checked the calculations within the experimental error in practically every case except for the steepest waves where stray capacities become of importance. In all such cases, the oscillogram after being checked carefully was assumed to be correct.

Circuit Arrangements

The slowest waves were obtained with the circuit given in Fig. 2 in which the condenser C was charged slowly by the use of a motor driven regulator connected in the primary of the charging transformer. The

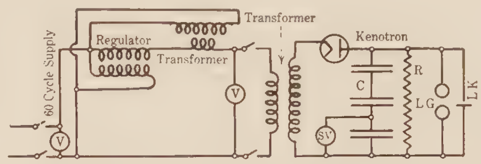


FIG. 2—CONNECTION DIAGRAM FOR SLOW WAVES USING MOTOR-DRIVEN REGULATOR
Time to reach crest 20 min. 55 sec.

reduction gears were such that, for the longest wave front, 22 minutes were required to reach a crest value of 25 kv. The limit of this method was about a 12-second front.

Other circuits used were similar to that shown in Fig. 3, in that a capacity C_1 was allowed to discharge in another capacity C_2. By varying the amount of capacity employed, together with appropriate values for series resistance connected between the condensers, the desired changes in wave front were obtained. A sphere-gap was used in series between the two condensers for the steeper waves, while with the slower waves, using this type of circuit, a kenotron was connected between the two condensers and the transient initiated by heating the filament at the proper time.

Considerable difficulty was experienced with the steepest waves in decreasing the amount of oscillation on the wave front. The rate of voltage rise was ex-

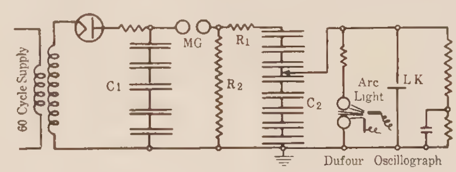


FIG. 3—CONNECTION DIAGRAM FOR VOLTAGE TRANSIENTS
Time to reach crest 1.0 sec.—0.1 microsecond

tremely rapid, being 100 kv. per microsecond. The final circuit used was physically quite small with all connections made with conductors having a high uniform resistance to aid in damping out the oscillations. Such a wave front is shown in Fig. 13.

Results—Effect of Changes in Wave Front

The Lichtenberg figures were taken, using a piece of plate glass 20.3 cm. × 25.4 cm., 3.8 mm. thick, with a cylindrical brass electrode 1 cm. in diameter in contact with the photographic film. The films, which were East-

man's super speed portrait films, were placed on the glass plate with the emulsion side in contact with the electrode. On the reverse side of the glass plate and opposite the electrode was a lead foil so connected that the electrode and foil was of opposite polarity. The parts were arranged in a light-tight box with the electrode projecting, to which connections were conveniently made, as shown in Fig. 4.

The results are plotted in terms of the radius of the

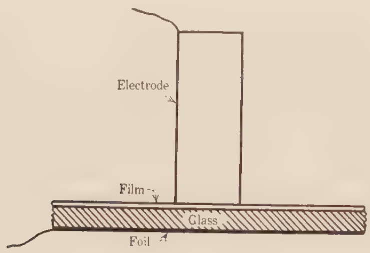


Fig. 4—Arrangement of Parts of Lichtenberg Camera

figure plotted against slope of the wave front in volts per microsecond for five voltages, 5.5 kv., 9 kv., 12 kv., 17 kv., and 25 kv. (All voltages are crest values). The curves for the positive figures are given in Fig. 5 and for the negative figures in Fig. 6.

Notwithstanding the precautions taken to control all of the known variables, the plotted points show considerable variation which is most marked with the shorter waves and at 17 kv. and 25 kv. For all voltages, the positive figures increase in size as the wave becomes steeper, until a rate of rise of between one kv. per

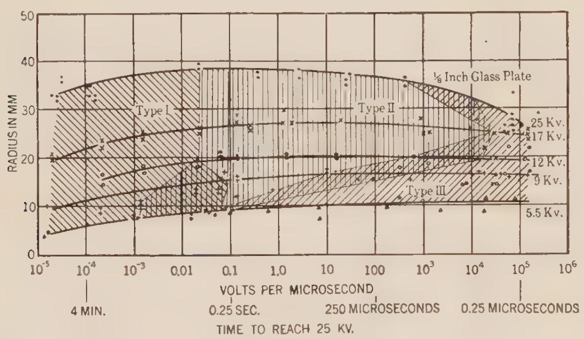


Fig. 5—Variation of Positive Lichtenberg Figures for Different Crest Voltages and Rates of Voltage Rise

microsecond and 10 kv. per microsecond is reached. With wave fronts steeper than this, which corresponds to about a 60-cycle front, the lower voltage figures remain constant in size while the 17-kv. and 25-kv. figures decrease somewhat at the steepest points. Fig. 5 has been divided into three zones which are determined from the appearance of the positive figures and will be discussed in connection with the different types of figures.

The negative figures were less satisfactory at the slow rates of voltage rise than were the positive figures, it sometimes being difficult to separate what appeared to be corona from the Lichtenberg figure. The results do indicate a rather abrupt increase in the size of the negative figure between 0.001 volts per microsecond and 0.01 volts per microsecond. As the voltage rises faster and faster, the negative figure increases in size, the greatest percentage change occurring with the lower voltages. For instance, the figure at 5.5 kv. increases from about 0.2 mm. to 13. mm. when the front changes from 0.01 volts per microsecond to 100,000 volts per microsecond. At 9 kv. the radius changes from 0.5 mm. to 2.4 mm. when the wave front changes through a similar range. The radius at 25 kv.

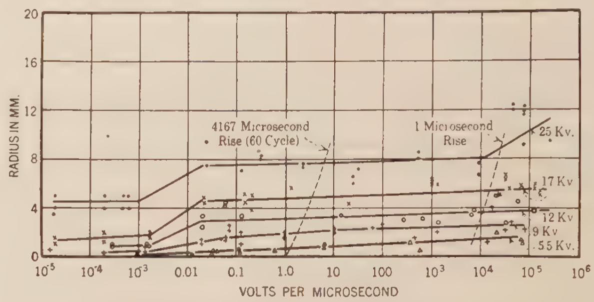


Fig. 6—Variation in Size of Negative Lichtenberg Figures for Different Crest Voltages and Rates of Voltage Rise

shows a sudden increase for fronts steeper than 10,000 kv. per microsecond.

Using the curves in Figs. 5 and 6 as representing the average values from the data, calibration curves have been drawn as given in Fig. 7. These curves show that the average positive figures are not appreciably affected by wave front except for the highest voltage and steepest front. The variation between the slowest and fastest waves for the negative figures is much

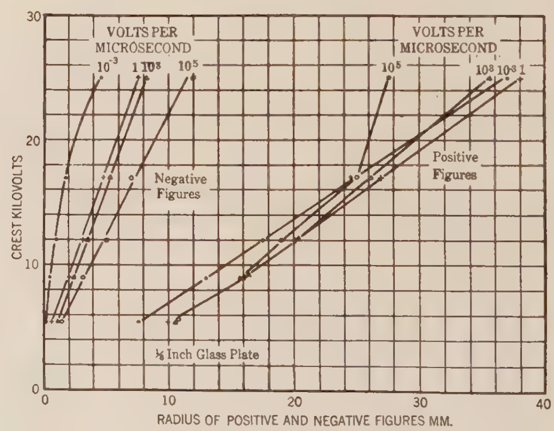


Fig. 7

greater than for the positive and should be considered when determining the voltage from a negative figure. At 17 kv., an increase of nearly 50 per cent takes place when the wave front changes from that corresponding to a 60-cycle wave to one which rises to 17 kv. in 0.1 microsecond, while, for lower values of crest voltage,

the variation is much greater. Some idea of the wave front may be determined by the comparative sizes of the positive and negative, but there is sufficient variation among pictures at the same wave front to make such a procedure doubtful for everything except very approximate results.

Appearance of the Figures

It is possible to divide the positive figures according to appearance into three definite type forms with respect

Fig. 8—Lichtenberg Figures Produced by a Very Slow Rise in Voltage (Type I—Positive Figures)

A. *P L*—20519 *R* 17 kv. in 840 sec. B. *P L*—20512 *R* 25 kv. in 85 sec.

to rate of voltage rise on the electrode. These three types are shown in Figs. 8, 9, and 10, type I being the slowest while type III represents the greatest rates of voltage rise.

Type I consists of fine straight lines emanating from

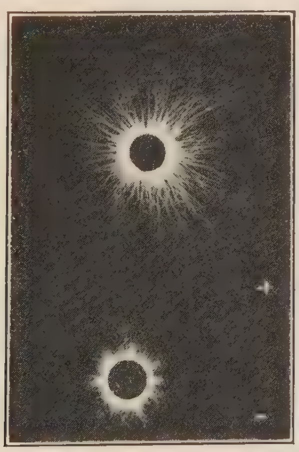


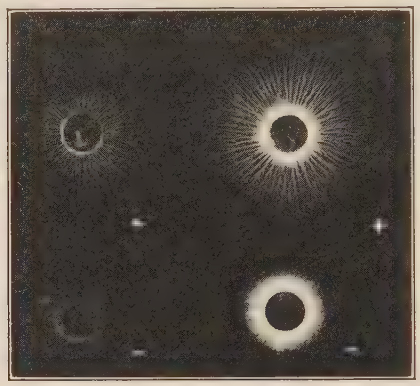
Fig. 9—Lichtenberg Figures Produced by a Fast Transient (Type II—Positive Figure)

P L—20573 *L*—21.6 kv. in 48 microseconds

the center and perhaps extending only partially round the entire electrode. The appearance is much like that of fine hair being blown out by some force at the center. As the rate of voltage rise becomes smaller, both the number of hairs and their length decrease until, in one case with a 6-second wave at 5.5 kv. crest, only five hairs were found, their length varying from 7.5 mm. to 8 mm. However, with a 6-minute front at the same crest voltage, the length of the hairs had been reduced to 4 mm., while the number of hairs had increased to perhaps 30 or 40, bunched in two or three small tufts. Some representative type I, positive figures are shown in Fig. 8.

The negative figures become smaller and smaller with decreasing rates of voltage rise until they disappear altogether or become so indefinite and indistinct that they cannot be measured.

In appearance, type II figures are quite different from type I being characterized by crooked lines which are likely to have sharp turns or elbows near the ends and usually split or branching. Sometimes short projections like thorns appear, but these belong more



A B

Fig. 10—Lichtenberg Figures Produced by Very Fast Transients. (Type III—Positive Figures)

A. *P L*—20607 *L* 7.3 kv. in 0.1 microseconds. Produced by transient shown in Fig. 12

B. *P L*—20605 *R* 17.8 kv. in 0.15 microsecond. Produced by transient shown in Fig. 13

to type III than to type II. Fig. 9 shows a typical figure of this type. The so-called slips are quite likely to have type II figures at the ends, even though the body of the figure is of another type. It should be noticed, also, that with type II figures, there is almost no crossing of lines even though the voltage was sustained for an appreciable length of time compared to the wave front.

The figures which have been called type III exhibit characteristics very different from either type I or type II. Type III figures as shown in Fig. 10 are recognized by their straight radial lines, having rather broad bases with splits and thorns. In type III figures, the lines do not cross and once seen it is not difficult to recognize a figure of this type indicating as a rule waves of quite steep fronts.

The voltage and frequency at which the three different types of figures are found are shown in Fig. 5 where the three types of figures are indicated. Some overlapping takes place where two types are found in the same

figure. At the 5.5 kv., it is interesting to note that the range of wave fronts over which type II figures appear is very small, and in fact they are not found alone at this voltage, always being mixed with either type I or type III figures.

The negative figures undergo considerable change in appearance as the wave front becomes steeper, but the change is gradual and it is not possible, using the data now available to draw definite limits or to divide them into types. In Figs. 9 and 10 representative negative figures are given, corresponding to the wave fronts shown in Figs. 11, 12 and 13. The slow negative waves as in Fig. 8 show a rather hazy indefinite outline with a tendency to concentrate in tufts. These figures are difficult to measure and look much like photographs of corona.

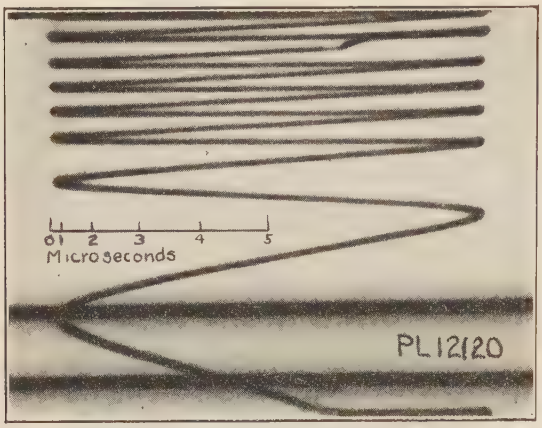


FIG. 11—DUFOUR OSCILLOGRAM OF TRANSIENT VOLTAGE

21.6 kv. in 48 microseconds. Corresponding to Lichtenberg Figure shown in Fig. 9.

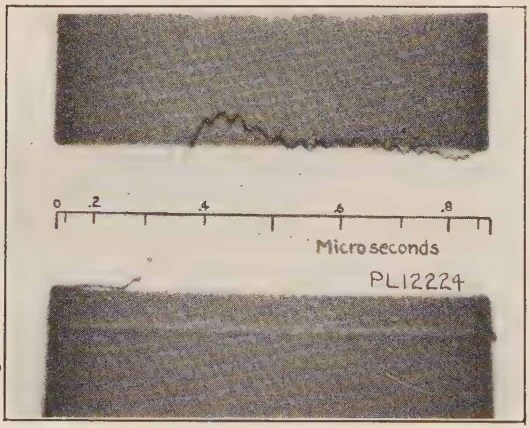


FIG. 12—DUFOUR OSCILLOGRAM OF TRANSIENT VOLTAGE RETOUCHED

7.3 kv. in 0.1 microsecond. Corresponding to Lichtenberg Figure shown in Fig. 10.

With steeper waves, as in Fig. 9, radial sectors of exposed film appear with more or less definite unexposed space between. Superimposed, many short crooked lines are frequently found not often extending beyond the exposed radial portion. While this form of negative is easier to measure than that obtained with the very slow waves, yet the limit of the figure is not sharply defined.

Very short waves produce a negative as in Fig. 10 in which the radial sectors are clearly defined and the limit of the figure is quite definite. Not only are the sectors more sharply defined but the width at the circumference of the figure is reduced, the space being occupied by a larger number of sectors. While crooked lines superimposed on the figure appear frequently, they are often less prominent than those seen with slower waves as in Fig. 9.

OSCILLOGRAMS

Three oscillograms are shown in Figs. 11, 12, and 13 to indicate the form of waves actually applied to the photographic film when taking the Lichtenberg figures.

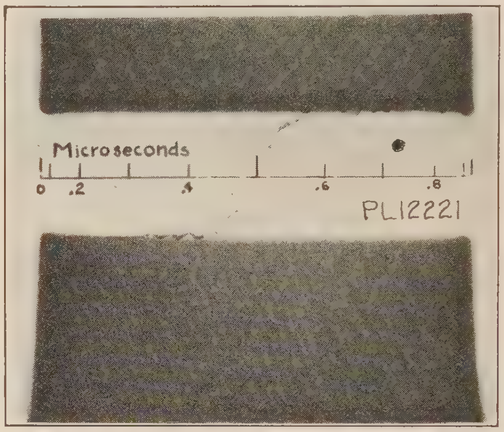


FIG. 13—DUFOUR OSCILLOGRAM OF TRANSIENT VOLTAGE

17.8 in 0.15 microseconds. Corresponding to Lichtenberg Figure shown in Fig. 10.

These oscillograms were taken with the Dufour cathode-ray oscillograph and show some of the wave fronts used in making the Lichtenberg figures shown in Figs. 8, 9, and 10. In Fig. 11 is shown an oscillogram of the wave taken at the same time as film PL-20573L shown in Fig. 9. This film shows that the voltage rose to its maximum (21.6 kv.) in 48 microseconds the average rate of voltage rise being 450 volts per microsecond while the maximum rate is 1800 volts per microsecond. The film shows that the final voltage was attained without oscillation and that the voltage dropped very slowly compared to the front after reaching its crest. All of the waves used in this investigation, as a rule, had long tails as compared with the front, so as to be sure that the tail did not disturb the results.

As the time to rise to maximum voltage was reduced, the difficulty of getting a smooth wave increased, but that a fair degree of success was finally attained is seen in Fig. 12. This film shows that a voltage of 7.3 kv. was reached in 0.1 microsecond which is equiva-

lent to an average rate of rise of 73,000 volts in one millionth of a second (Lichtenberg figure PL-20607L, Fig. 10). While some oscillations are present, their amplitude does not appear to be sufficient to make them a matter of importance.

Another film in which a still greater rate of voltage rise is recorded is shown in Fig. 13. Here the average rate of rise of potential is 120,000 volts per microsecond. The Lichtenberg figure corresponding to this wave front is shown in Fig. 10 film PL-20605R.

Films similar to these were taken for every voltage application when making Lichtenberg figures and it can be stated that for waves having a longer front than 10 microseconds any oscillations which were present were negligible and that for the shortest waves such oscillations did not exceed 20 per cent of the crest voltage.

It is interesting to note that when working with these figures the impression is gained that the presence of oscillations increases the distinctness and clarity of the figures and that this is particularly true of the negative. While this as yet is only an impression, yet the cleanest figures always were associated with the waves having oscillations on the wave front.

Conclusions

As a result of this investigation, it can be definitely stated that the size and appearance of both positive and negative Lichtenberg figures are dependent on the wave front as well as on the crest voltage.

Throughout the range of wave fronts probably found in service, the size of the positive figure is not much changed by a change in wave front only, except at voltages close to the upper limit of potential where a decrease in the size of figure is indicated with very abrupt fronts.

The positive figures may be divided into three type forms which are partly determined by wave front and partly by the value of the crest voltage. It is possible to gain some idea of the steepness of the front from the appearance of the positive figure.

The size and appearance of the negative figures are considerably affected by changes in wave front, the steepest waves always giving the largest figures. The percentage change with a constant crest voltage applied is greatest for the lower voltages. The change seems to be great enough so that it cannot be neglected. The negative figures change in appearance with increasing steepness of wave front, but the changes are so indefinite that it is only possible to state that a particular negative figure probably represents a fast wave or a slow wave.

No value is given for the possible variation in radius of figures with identical wave front from the average, although the usual variation is probably not greater than 25 per cent. Occasionally, one will be found where the figure is 50 per cent or more, larger or smaller than the average for that particular wave. There seems to be some tendency for the greatest variations to occur with the steepest wave fronts.

The curves which have been given apply to apparatus of certain characteristics and should not be applied to figures taken with a different dielectric than used here or for other different conditions. It seems likely, however, that similar results will be found with other apparatus constants although the values would be different.

Additional work is being done with the cathode-ray oscillograph in an effort to determine how the Lichtenberg figures grow and the reasons for the various characteristics which they exhibit.

The author wishes to express his appreciation of the work of E. M. Duvoisin and T. Brownlee, who have supplied all the figures and most of the oscillograms, and to E. J. Wade for his valuable assistance, particularly in arranging the circuits so as to avoid oscillation.

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CORRESPONDENCE

To the Editor:

On page 783 of the issue of the Journal of the A. I. E. E. for August, 1926, there is an obituary notice of the late Charles E. Scribner, from which I quote as follows: "Mr. Scribner was a well-known electrical inventor, having taken out almost 500 patents during the course of his active service. After the death of Steinmetz, he was credited with holding more patents in the electrical field than any other man, save his friend, Thomas A. Edison," etc., etc.

In the interest of accuracy, I wish to state that Professor Elihu Thomson, of the General Electric Company, has approximately 700 United States patents alone, most of them, of course, relating to the electrical field.

John A. Mc Manus

Electrical Machinery

Annual Report of Committee on Electrical Machinery*

BY B. L. BARNS, Chairman of Subcommittee on Annual Report

To the Board of Directors:

The activities of this committee during the past year have been carried out on a plan of organization comprising a number of subcommittees as outlined in Mr. H. M. Hobart's report to the President and Board of Directors on the Development of the Activities of the A. I. E. E. Technical Committees under date of January 19, 1925. This report is under consideration by the Committee on Technical Activities to determine the advisability of recommending it in whole or in part for all of the technical committees. The scope of the Electrical Machinery Committee's activities has been based on the recommendation contained in a report made by Mr. A. W. Berresford as chairman of a Special Committee to Review Technical Activities of the A. I. E. E. under date of January 23, 1924.

During the past year the Electrical Machinery Committee has been more active in standardization work. A subcommittee on standardization has been organized under the chairmanship of Mr. J. C. Parker which is functioning in an advisory capacity to the Institute's Committee on Standardization in matters concerning electrical machinery. The committee on Electrical Machinery, through a subcommittee under the chairmanship of Prof. V. Karapetoff, is also sponsoring research work affecting standardization and advancements in the art and is collaborating with the Committee on Research.

That part of the Electrical Machinery Committee's work which has resulted in the most tangible accomplishments has been the procuring and reviewing of suitable papers on various subjects which have been presented under the auspices of this committee at the regular and regional meetings. The following table shows the number of papers under different classifications that have been presented during the year.

Factors which affect design of electrical machinery	5 papers
Generator design and construction	8 papers
Motor design and construction	4 papers
Transformer design and construction	2 papers
Total	19 papers

*Committee on Electrical Machinery:

H. M. Hobart, Chairman, General Electric Co., Schenectady, N. Y.
J. C. Parker, Vice-Chairman, Brooklyn, N. Y.

C. A. Adams,	L. L. Elden,	P. M. Lincoln,
H. C. Albrecht,	G. Faccioli,	A. M. MacCutcheon
B. F. Bailey,	W. J. Foster,	F. D. Newbury,
B. L. Barns,	Harold Goodwin, Jr.	N. L. Pollard,
B. A. Behrend,	J. I. Hull,	R. F. Schuchardt,
A. C. Bunker,	V. Karapetoff,	C. E. Skinner,
James Burke,	A. H. Kehoe,	A. Still,
Walter M. Dann,	A. E. Kennelly,	R. B. Williamson.

Presented at the Annual Convention of the A. I. E. E., at White Sulphur Springs, June 21-25, 1926.

In preparing a review of the development or advancement of the electrical machinery art one is inclined to turn first to those new types of machines that have developed and those machines which represent new records for high rating or size or voltage. The research work, whether it be mathematical, chemical, or physical, by which new types and high ratings are made possible is less spectacular but of fundamental importance. The enumeration of new high water marks of ratings may not of itself appear to be an index of an advancement of the art but there are often many details and problems involved in the successful design and manufacture of such machines involving real pioneer work. Nor is all the engineering pioneer work confined to setting new records of large size. If we would but examine them carefully we would find research and ingenuity written all over the smaller apparatus that we see about us every day and take for granted.

It is, of course, beyond the scope of this report to record even briefly the solution of the many problems involved in the perfecting of new developments, for time and space would not permit, nor is such detailed information available for that purpose. In considering the remarkable things that have been accomplished in building huge machines we should not overlook the importance of the development and improvement of the small apparatus upon which the expansion and growth of the electrical industry is so largely dependent.

Again we take a considerable measure of satisfaction in recording new attainments reached in higher ratings of machines which have been put into successful operation. New records have been made for large capacity all along the line. Larger ratings than ever before obtained have been built in transformers, synchronous motors, induction motors, d-c. motors, horizontal-shaft alternators and turbo alternators.

The following review is classified under headings for convenience in preparation and reference and an attempt has been made to include under each a bibliography of the more important articles that have been published during the year. An attempt has also been made to cover the more important developments that have taken place in Europe as well as in America (the United States and Canada). An apology is offered if important articles or developments have been omitted. Such omissions are entirely accidental.

Research

This committee now has the following subjects under consideration and it is probable that as investigations advance sufficiently to mention definite results they will be described in the form of papers for presentation at

Institute meetings. These topics are mentioned not so much to record the actual progress made by the Committee as to indicate problems of importance brought to the Committee's attention.

Effect of Altitude on the Dielectric Strength of Insulations. An investigation has been proposed to determine whether it is desirable to draw a distinction between apparatus that is to be used at sea level and high altitudes as regards the insulation tests.

Influence of Expansion and Contraction of Conductors on Insulation Deterioration in Long Machines. This subject has already received a great deal of attention and some valuable experimental work has been done. This subject is becoming of greater importance with the increasing capacities of turbo alternators. Further investigation has been suggested as desirable.

Surge Tests of Insulation. An investigation of this subject is being undertaken to determine whether it is desirable or practical to standardize a test of this sort on the insulation of machines that may be subjected to transient high-voltage conditions.

Hot Spots in Cores of Alternators. Observations made by engineers in Europe have indicated that higher temperatures may be reached in the slots at the ends of a turbo generator core than in the slots at the center of the core. Manufacturers in the United States have reported that they have been unable, from tests made on machines of American make, to substantiate this statement. This may be due to the difference in the design of end windings in Europe and in America.

Evaluation of Conventional Losses. The present A. I. E. E. Standards assign conventional values to certain losses that are known to exist. It is felt that methods should be devised by which these losses may be determined by tests so that the design and tests may be reduced to a more exact science and due credit may be given to designs that are especially meritorious in this respect.

Calorimetric Method of Determining Losses in Alternators. The feasibility of determining the losses and efficiency of alternators by calorimetric methods which are based on the temperature rise of the cooling medium is being investigated.

Stability of Alternators. As distribution systems increase in size and the use of long, high-voltage transmission lines is extended, the subject of stability of generators becomes of greater importance. A study of the possibility of the evaluation or definition of generator stability is being made so that this characteristic may be specified.

Relation between Dielectric Tests on New and Used Machines. This subject has arisen from a consideration of recommended practise in checking the condition of the insulation of a machine that has been in operation for some time.

Non-Destructive Physical Tests on New and Used Insulation. Physical tests of insulation have been suggested as being desirable; accordingly, the subject is being investigated.

During the past year research work has been done on the following subjects that come within the scope of this committee's activities:

Effect of Altitude on Ratings of Electrical Machinery. This investigation was undertaken for the purpose of providing a satisfactory revision of the present A. I. E. E. rules which have been recognized as not being entirely satisfactory.

Copper Eddy-Current Losses. A theoretical foundation for the calculation of no-load copper eddy-current losses in machines has been presented.

Motor Band Losses. Methods of calculating losses in the binding bands of armatures of direct-current machines have been made practicable.

Heating Curves of Electrical Machinery. A further study of the prediction of the heating curves of machines has been presented.

Alternator Short Circuits. The calculation of the transient phenomena resulting from short circuits of the armature windings of alternators has been a subject of study for many years and an accurate method of predetermining the value of the short circuit current is becoming more and more important as the generating capacity of power systems increases from year to year. Two papers have been presented to the A. I. E. E. during the past year dealing with this subject. One of these papers treats the subject on the basis of Kirchoff's law that the vector sum of all the currents at a junction is equal to zero. The other paper is based on the constant linkage theorem, viz: "In a circuit having zero resistance the algebraic sum of the flux linkages of the circuit must remain constant."

Measurement of Stray Load Losses in Alternators. A paper has been presented which has suggested a different method of determining stray load losses than that specified in the present standards, and results of tests have been given.

Ventilation of Turbo-Alternators. During the year this work has been carried forward to a conclusion by the use of small models. Previous calculations and empirical formulas have been checked so that now a complete solution of the complex problem of measuring static pressures in a fluid moving at considerable velocity can be successfully obtained.

Theory of the Synchronous Induction Motor. This subject has received considerable attention in Europe and a number of excellent treatises have been written.

Hydrogen as a Cooling Medium. A further investigation of the problems incident to the use of hydrogen as a cooling medium has been undertaken.

Characteristics of Synchronous Machines. Blondel's theory of two reactions has been extended to include the effect of harmonics and of field excitation in the quadrature axis.

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Additional Losses in Turbo Alternators, Robert Pohl, *Elektrotechnische Zeitschrift*, Aug. 6, 1925, Vol. 46, pp. 1182-1185.

VENTILATION OF ELECTRICAL MACHINERY

Ventilation, one of the fundamental considerations in the design of electrical machinery, has been a subject of very active study and experimentation. Because the design of turbo alternators involves a relatively greater need of a knowledge of the phenomena incident to the flow of gases through irregular passages, experimental work has been carried out to determine the forms of fans, bafflers and internal ducts which would give the desired cooling effect with a minimum of windage losses by introducing into new machines alternative ventilation schemes which were tried out when they came to test. In this way much valuable and accurate information has been obtained which has been free from some of the uncertainties of theoretical considerations of a very complicated problem. Nevertheless, considerable help has been obtained by building small models and testing them under laboratory conditions to check and verify principles that have been deduced by a theoretical treatment of the problem. Models have been constructed to represent the vent ducts and air passages in the stator core of a turbo alternator and tested to determine the drop in pressure in the several parts of the passage ways. In this way data was obtained by which close approximation can be made of the amount of pressure required to force a given quantity of air through a given machine. Other models have also been tested to determine the most efficient shapes of slot retaining wedges in stators and the best arrangement of spacers in the internal ventilation ducts. All of this work has contributed toward better designs not only of turbo alternators but also of other types of machines.

This committee's report of last year made mention of an investigation into the use of hydrogen as a cooling medium for rotating machinery. The results of this have been published and this method seems to have many advantages that would make it desirable for commercial application and some operating engineers are looking forward to the time when it will be found feasible to use hydrogen for this purpose. Some of the new machines that are now being purchased are being arranged so that they may be readily adapted to the use of hydrogen when the problems peculiar to its use are finally solved.

A few years ago the recognized need of providing clean air for the ventilation of machines, especially large capacity turbo alternators, was met by the use of air cleaning and air washing apparatus which took air from outside the building, cleaned it, and discharged it outside again after it has passed through the machine, probably cleaner than when it came from the washer. This veritable throwing away of perfectly clean air appeared to be an uneconomical procedure and during the past year or more a more rational arrangement of a closed system has been used particularly for large turbo alternators. This system recirculates the same air, cooling it by passing it over water cooling pipes. The advantage of this arrangement has been recognized during the past year for application to other types of machines, it having been adopted for hydroelectric plants and substation equipment. The closed ventilating system necessarily presupposes an abundance of cooling water at low cost.

During the past year an ingenious arrangement has been devised for cooling heavy duty bearings of substation machinery where the water supply for such purposes is expensive. This scheme consists of a closed water circulating system so arranged that the water is cooled by the air used to ventilate the machine.

Although for a number of years sales campaigns have been carried on advocating the use of small fans to increase the heating capacity of radiators in very cold weather this idea has not been applied to the cooling of transformers until this year. By the use of jets of air directed over the surfaces of self-cooled transformers the convection of heat has been greatly accelerated. This development gives promise of many possibilities.

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TESTING ELECTRICAL MACHINES

A renewed interest has been shown in the accurate determination of load or stray losses of rotating machines. The assumption that is made in the present A. I. E. E. Standards that the measured short circuit core loss is equal to the load loss is generally considered to be far from correct in certain types of alternators and there is a general desire for a more accurate method of determining these losses that would be suitable for application to commercial testing. A paper which was presented at the Midwinter Meeting advocated a method of test which was based on measuring the synchronous motor power input when running light under conditions of leading and lagging currents. The discussion of this paper indicated that a calorimetric method of measuring losses has been in use in one of the large factories for several years and that this method is being studied by others. The calorimetric method makes use in different ways of the observed temperature rise of the air passing through the machine. Since closed ventilating systems are being more generally used the determination of the losses by the measurement of the heat absorption by the air cooling equipment seems to offer a satisfactory method of test. These calorimetric methods do not, however, offer means of direct measurement of the so-called load losses but are more suitable for the determination of the total losses under actual load condition. This committee is desirous that suitable commercial test methods be developed for a more accurate determination of the efficiency of large synchronous machines than is now described in the A. I. E. E. Standards.

The testing of large machines on power house settings such as water wheel driven alternators often involves the measurement of losses by the deceleration method. During the past year a chronographic method has been devised for obtaining a simultaneous record of time and revolutions on a paper ribbon.

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TURBO-ALTERNATORS

In this Committee's report of last year, mention was made of a 62,500-kv-a. 1200-rev. per min. turbo generator which had recently been put into operation as the largest single-shaft unit that had been built. During this year two machines of this capacity but of 1800 rev. per min. have been put into successful operation. The step up from 1200 rev. per min. to 1800 rev. per min. has been made possible by the more skillful design of the electrical parts, a better proportioning of the mechanical parts, and more extended multiple ventilation. This increase in speed makes it possible to further extend the upper limit of rating for single-shaft machines to such an extent that two 60,000-kw. units are now under construction and 75,000-kw., 80 per cent power factor generators are being considered. A machine of this rating at 1200 rev. per min. would present difficulties in manufacture because of the great weight of the rotor. Another large turbo alternator that was put into service the past year is rated 66,660 kv-a., 1500 rev. per min., 25 cycles. In France one of 60,000 kv-a., 1500 rev. per min., 50 cycles, is about ready to be put into operation. The description of this generator in a paper presented before the Institute brought out in the discussion some interesting information on the relative design practises in Europe and the United States. The French machine employed deep slots in the stator core for the dual purpose of increasing the reactance and providing axial paths for ventilation. Another feature is the much smaller ratio between saturation and impedance ampere turns than has been considered good practise in America. American practise has considered it necessary to maintain this ratio at near unity while European practise allows it to be as low as 0.5. This difference may possibly be accounted for by the difference in operating practise on the two continents. In America the apparent desire of the operators is to get the maximum output from the generator throughout its period of life, while in Europe, it is said, a generator is usually operated at slightly less than its rated capacity. Another factor has been the general practise in Europe to employ voltage regulators to care for the swings in load and supply the necessary excitation to prevent the

generators from falling out of step while in the United States operating people have insisted upon generators that may be hand regulated and which are not dependent upon automatic regulation for their stability.

It is interesting to note that designing engineers now predict the possibility of building machines having ratings of 75,000 kw., 80 per cent power factor at 1800 rev. per min., 100,000 kv-a. at 1500 rev. per min., for 50 cycles and 40,000 kv-a. at 3000 rev. per min. for 50 cycles. A 25,000-kw., 3000-rev. per min. machine has been built in Europe. It is the opinion of a leading engineer that if greater capacities than 75,000 kw. are demanded by the operating companies they will be obtained by advances in the design and materials applied to the four-pole generator rather than a return to a six-pole design. For very large units there are advantages in the cross-compound arrangement or multiple-shaft design involving two or more generators. A unit of this type having a house generator, in addition to the two main generators and with a total rating of 77,000 kw. has been completed during the past year and another of 80,000 kw. is under construction. An order has recently been placed for a two-generator unit rated at 90,000 kw. Triple shaft units with three generators of combined capacities of 160,000 kw. and 200,000 kw. are being considered.

These very high generator ratings have involved problems concerning mechanical stresses in the rotor due to centrifugal forces and deflection, insulation of the rotor windings and ventilation of the stator. Centrifugal stresses have been provided for by the development of special alloy steels. The limitations of rotor deflection in its relation to critical speed have been largely eliminated by a better knowledge of the mechanics of the problem. Whereas before this was so well understood it was believed that the rotor speed should be well below the critical speed, now the designers are concerned only that the normal speed must not approach any multiple of the first critical speed. Experience has shown that the critical speed is not dependent only on the weight and length of the rotor but that it is influenced by the type and proportions of the stator frame and bearing supports and the design of these parts offers a means of control. The very great pressures on the rotor winding insulation coupled with the expansion and contraction resulting from changes of temperature has necessitated the development of types of insulation for the end coils that will withstand these destructive conditions. In the matter of ventilation, schemes of providing a number of multiple paths have been devised to obtain the equivalent of a short core machine. In some cases as many as 28 parallel paths are provided. For the ventilation of the smaller generators fans mounted on the shafts inside the end bell housing have been used although separate motor driven fans would be more efficient. This arrangement has the advantage, however, of eliminating a separate auxiliary which if it failed to operate would cause the removal of the generator from service. The fan capacity required for the very large generators has exceeded the limit of the type that can be mounted on the rotor and separate fans or blowers are now a necessity. With well designed external blowers, having an efficiency of 65 per cent, a saving in the total losses of the machine would amount to approximately 0.1 to 0.2 per cent at rated load. On the larger machines it is often feasible by the use of external blowers to build them with smaller diameters than would be possible with fans on the rotor. Under such conditions the external blower ventilated machine may show an efficiency of from 0.3 to 0.4 of a per cent higher than the machine with fans attached to the rotor. Besides the better efficiency this arrangement affords another important advantage in that the air passes through the air coolers of a closed system after leaving the fans and before it enters the generator thus extracting the heat put into it by the fans. A material reduction in the temperature of the air entering the generator is obtained as compared with its temperature when the fans are assembled on the shaft. The closed ventilating system with fin-type radiator coolers is now being used almost universally for turbo alternators.

During the year there have been improvements in the Emmet mercury turbine with resulting higher efficiencies.

The 3000-kw. 3600-rev. per min., 20-stage turbine for operation at a steam pressure of 1200 pounds which was mentioned in our report of last year has been put into successful operation.

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Water-Wheel Driven Alternators

American hydroelectric practise still favors the vertical shaft arrangement of alternators to such an extent that about 80 per cent of the water wheel

generators are of this type and the arrangement is more or less standardized with a spider or bridge spanning the top of the armature frame for supporting the thrust bearing which carries the weight of the generator rotor and the water wheel runner. Two years ago several units were built with the thrust bearing beneath the revolving field and no bearing or superstructure above the rotor except a cover or housing. Although there seemed to be a number of advantages to be gained by this so-called umbrella type no further machines have been built 'til this year. A 6250-kv-a., 138½ rev. per. min. generator of this type is now under construction. One manufacturer is using a fabricated construction of welded steel plate to a large extent for the armature frames. The closed ventilation system has been adopted in one large water power station.

During the year a rather formidable number of large capacity alternators both horizontal and vertical shaft have been under construction or installed and the following incomplete list will serve to indicate to what extent machines of large ratings are being used.

3-37,500 kv-a.	12,000 volts,	120	rev. per min.	vertical shaft
3-18,750 kv-a.	6,600 volts,	100	rev. per min.	vertical shaft
2-29,000 kv-a.	.... volts,	300	rev. per min.	vertical shaft
2-25,000 kv-a.	13,200 volts,	450	rev. per min.	vertical shaft
2-20,000 kv-a.	11,000 volts,	200	rev. per min.	vertical shaft
1-17,000 kv-a.	6,600 volts,	375	rev. per min.	vertical shaft
1-17,500 kv-a.	6,600 volts,	100	rev. per min.	vertical shaft
2-25,000 kv-a.	6,600 volts,	90	rev. per min.	vertical shaft
2-54,000 kv-a.	12,000 volts,	187½	rev. per min.	vertical shaft
2-13,500 kv-a.	6,600 volts,	277	rev. per min.	vertical shaft
4-16,000 kv-a.	11,000 volts,	133	rev. per min.	vertical shaft
3-20,000 kv-a.	11,000 volts,	330/360	rev. per min.	vertical shaft
2-15,625 kv-a.	11,450 volts,	257	rev. per min.	vertical shaft
2-25,000 kv-a.	12,000 volts,	300	rev. per min.	vertical shaft
2-18,750 kv-a.	12,000 volts,	150	rev. per min.	vertical shaft
2-15,000 kv-a.	6,600 volts,	171	rev. per min.	vertical shaft
1-21,000 kv-a.	11,000 volts,	138½	rev. per min.	vertical shaft
1-12,000 kv-a.	12,500 volts,	128½	rev. per min.	vertical shaft
1-12,000 kv-a.	2,400 volts,	250	rev. per min.	vertical shaft
8-12,500 kv-a.	14,000 volts,	100	rev. per min.	vertical shaft
2-10,600 kv-a.	12,000 volts,	120	rev. per min.	vertical shaft
2-36,000 kv-a.	6,600 volts,	100	rev. per min.	vertical shaft
2-30,000 kv-a.	6,600 volts,	112½	rev. per min.	vertical shaft
2-10,000 kv-a.	6,600 volts,	180	rev. per min.	vertical shaft
2-33,000 kv-a.	11,000 volts,	360	rev. per min.	horizontal shaft
1-33,000 kv-a.	13,200 volts,	360	rev. per min.	horizontal shaft
2-25,000 kv-a.	11,000 volts,	450	rev. per min.	horizontal shaft
1-20,000 kv-a.	11,000 volts,	375	rev. per min.	horizontal shaft
1-14,444 kv-a.	6,600 volts,	600	rev. per min.	horizontal shaft
1-13,000 kv-a.	12,000 volts,	500	rev. per min.	horizontal shaft
1-13,125 kv-a.	4,400 volts,	225	rev. per min.	horizontal shaft

Although the 65,000-kv-a. units at Niagara Falls are still the largest machines that have been built, larger alternators have been under consideration and will probably be built in the near future. The manufacturers are prepared to build the following maximum rated water-wheel driven alternators of the vertical shaft type and designed to meet the usual run-away speed requirements:

10,000 kv-a. at 720 rev. per min.
20,000 kv-a. at 600 rev. per min.
30,000 kv-a. at 514 rev. per min.
55,000 kv-a. at 400 rev. per min.
80,000 kv-a. at 300 rev. per min.
110,000 kv-a. at 200 rev. per min.
130,000 kv-a. at 100 rev. per min.

The use of welded steel plate stator frames and the substitution of a few separate sole plates for a continuous base ring has appreciably reduced vertical shaft generator weights. Comparisons of construction and actual weights indicate that American designs are at least twenty-five per cent lower than similar European machines.

The past year has set a new record in the maximum capacity of horizontal shaft water-wheel driven generators. Two alternators rated 33,000 kv-a. at 360 rev. per min. were built in the United States for a Brazilian plant and a third was built for a California plant. In Europe a 30,000-kv-a., 500-rev. per min. horizontal shaft alternator has recently been built which has an unusual rotor construction consisting of twin rotors each with its pole pieces and windings mounted side by side on the shaft in a common armature core. This construction was adopted to conform with certain shop and transportation facilities.

The use of automatic or remote control of hydroelectric units is extending. During the past year some 9000 kv-a. units have been put into successful operation being the largest yet constructed for this type of control.

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Diesel Engine Driven Alternators

There has been considerable activity during the past year in exploiting the use of Diesel engines as prime movers for stand-by plants. An installation of this type which is worthy of note consists of three 3125-kv-a, 80 per cent power-factor, 25-cycle, 125-rev. per min. units for the Panama Canal which are probably the largest generators driven by this type of engine.

Transformers

An important consideration in transformer work is the provision of means of dissipating the losses with sufficient rapidity to keep the temperature of the trans-

former within safe limits. In the past this has been accomplished by one of four methods, *viz:*

1. Air-blast, in which air is blown around and through the core and windings.

2. Self-cooled, in which the heat is transferred from the core and coils to the casing by an oil bath and then dissipated principally by radiation.

3. Water-cooled, in which the heat is removed from the oil bath by water cooling coils.

4. Oil-cooled, in which the oil bath is circulated through a cooling apparatus independent of the transformer.

A new method involving an old principle has gained much favor this year. This consists of directing jets of air upward and over the radiating surfaces thereby removing a larger part of the heat by convection than can be done by the natural circulation of air. Some very large transformers arranged for cooling by air jets have recently been completed. The rating of these oil-insulated, air-cooled distributed core type transformers is 30,000 kv-a., 220,000 volts Y, 125,000 volts Y, 10,640 volts delta at 60 cycles and 55-deg. cent. temperature rise by resistance.

The method in which the oil is cooled outside of the transformer tank is more generally used in Europe than in America. This year, however, some very large transformers arranged for this method have been built and installed in America. They are rated 20,000 kv-a., 50 cycles, 72,000-Y, 11,000-volt single-phase, and sea water is used as the cooling medium. Although air-blast transformers are not used to as great an extent as they were many years ago there is still a demand for them for installation in certain localities where the presence of large quantities of oil is considered to be a fire hazard. The largest air-blast transformer yet built was installed this year. It was rated 18,500 kv-a., 25 cycles, 11,800-3,300 volts three-phase and weighed about 43 tons.

The largest self-cooled single-phase transformers ever built were completed this year. They are rated at 20,000 kv-a, 72,450-Y, 13,800 volts, 60 cycles. Likewise the largest water-cooled transformers both in point of rating and physical size have been built this year. These are rated 28,866 kv-a., 220,000-Y, 66,000-Y, 10,750 volts, 60 cycles, single-phase. As will be noticed in the ratings of the above self-cooled and water-cooled transformers tertiary windings are being used to a large extent in large high-voltage power transformers. The tertiary windings being connected delta permit using the star connection for both primary and secondary windings. The tertiary winding also provides a means of connecting a condenser into the system for transmission line voltage regulation without using an independent transformer where the secondary voltage is too high for a condenser winding.

During the past year the largest and highest voltage transformers ever built in the British Empire were completed in Canada. These are designed for a rating of 25,000 kv-a., single-phase, 60 cycles, 154,000 volts and weigh 80 tons each. Twelve of these transformers were built on one order.

A German manufacturer has built the largest capacity transformer ever constructed. By removing the aluminum windings of a 60,000-kv-a. transformer that had been in operation for several years and substituting copper windings a three-phase transformer having a rating of 75,000 kv-a., 110,000 volts was produced. This transformer is now in successful operation.

Probably the most important development pertaining to transformer construction has been the further improvement of and extended use of transformers equipped with load ratio control or devices for changing taps without interrupting the load. Transformers of this type are being extensively used to regulate circulating currents between systems where the flow of energy is in either direction and where each system must maintain its voltage independently of the direction of the flow of energy.

One of the largest units of this latter type is a three-phase self-cooled auto-transformer rated 36,000 kv-a., 66,000 volts, 60 cycles. It is used as a tie between two 60,000-volt systems. The taps are arranged to give 10 per cent buck and 10 per cent boost in nine steps. The total weight of this transformer with operating mechanism and circuit breakers is about 73 tons.

The electrical circuit of this unit is novel in that double transformation is employed to secure voltage control. Electrically, the unit consists of two distinct transformers each provided with a high-voltage and low-voltage winding. The high-voltage windings of each transformer are connected to the 66,000-volt line, one being connected in shunt to the line and the other in series to the line. The shunt transformer contains the necessary taps and ratio adjusters by means of which fractions of the low voltage winding on the shunt transformer can be connected to the low-voltage winding on the series transformer. By varying the taps the desired amounts of voltage either bucking or boosting can be inserted in the high-voltage line through the series transformer. By thus placing ratio adjusters in a separate low-voltage circuit the switching apparatus is protected from abnormal voltages which may arise in the high-voltage lines.

It sometimes becomes desirable for the sake of greater insurance against interruption of service to separate the regulating function into a separate transformer. An interesting example of this consists of banks of three single-phase, self-cooled, power transformers rated 20,000 kv-a., 12,600-13,800 volts, 60 cycles, a three-phase, self-cooled, regulating transformer of 60,000 kv-a. capacity.

Transformers having arrangements for tap changing under load are also being extensively used for electric furnace work.

The extension of the idea of rural electrification has opened up a new field of design in small distribution

transformers for very high voltages. Some 100-kv-a., 110,000-volt transformers have recently been built for this purpose.

During the past year the largest potential transformers were built for use in America. These were designed for use between line and neutral of a 144,000-volt system. They have only one high-voltage bushing, the neutral being grounded to the cover.

The development of successful high-voltage transformers is assisted greatly by accurate knowledge of very high-voltage phenomena which can be obtained only by experimentation at voltages much higher than the actual transformer potentials. During the year a study has been made of transformer and other high-voltage insulation with a 2,000,000-volt lightning generator for the purpose of obtaining practical information in designing apparatus to resist the effects of voltages induced in transmission lines by lightning. High-voltage testing sets to provide voltages as high as 2,100,000 volts have been constructed. These consist of 350,000-volt transformers connected in series or in chains, each succeeding unit being insulated from ground by supporting it on insulating cylinders.

Improvements have been made in the temperature-indicating devices that are being used more generally to check the actual operating conditions of service transformers. A model has been produced which is suitable for use with subway transformers.

Of special interest to radio telephone engineers and enthusiasts is the development of a transformer for use with the ignition systems of oil heaters which successfully eliminates radio interference trouble, a serious objection to electric ignition in these devices heretofore. This transformer is provided with an internal magnetic blocking filter as well as low-voltage and high-voltage filters. During the past year the largest high-voltage oil-immersed reactors were constructed that have ever been built. They were rated 1300 kv-a., 3000 volts for operation on a 73,000-volt, 60-cycle circuit. A distinctive feature of these reactors is that they were provided with shielding coils to prevent the stray magnetic field entering the steel tank and setting up additional losses. Air-cooled reactors have presented a serious difficulty due to the fact that they would flash over when a failure occurred on the circuit in which it is connected if any conducting material were lodged between the turns. An investigation has been carried out to determine a suitable insulation for the conductor of this type of reactor which indicates that a heavy asbestos covering will prevent flashovers from this cause.

A new transformer connection having 100 per cent apparatus economy for transformation from two-phase to three-phase, or vice versa, has been devised which has been described in a paper presented to the Institute.

Some very large single-phase transformers that are quite novel in certain respects have been built recently in Europe for 16⅔-cycle railway work. They have three windings so arranged that power may be supplied from any one winding to either one or both of the other two. One of the two cores carries a 132,000-volt winding, the other carries a 66,000-volt winding and a 15,000-volt winding is divided into four parallel sections on both cores. It is stated that with this arrangement the bus bars and oil switches are not necessary on the 15,000-volt side. These transformers are rated 11,000 kv-a. and the total weight including oil is 117 tons.

A new protective device for large transformers has been developed in Germany which is called the Buchholz Relay. The operation of this relay is based on the fact that practically any trouble in an oil-insulated transformer will create gases which rise to the surface of the oil. A small amount of gas will cause the relay to operate. This relay will detect incipient troubles that will not actuate a current operated device and will disconnect the transformer before great damage is done. This relay can be used where the differential relay scheme cannot be applied.

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D-C. Machines

A new record has been set in direct-current motor capacity by the construction of an 8000-h. p., 40-rev. per min., single-armature blooming mill motor. Several 7000-h. p. reversing mill motors have been built and the power for the first edging rolls to be equipped with electric drive is supplied by two motors of 2000 h. p. each. The simplicity and flexibility of speed control of

direct-current motors make them very desirable for variable speed drives and there has been considerable activity in the construction of large motors for steel mill work.

A new type of armature winding has been developed and applied to many commercial machines. This winding, because of the shape of the coils, is called "Frogleg" and is a combination of a wave winding and a multiple winding arranged so that the armature is cross-connected by the wave winding and all cross connections at the commutator and at the back of the armature are eliminated. This type of winding provides complete cross connection which is very desirable for good commutation. The winding is arranged so that each slot contains four bars, two of which are in the wave winding circuit and two in the multiple winding circuit, and each commutator bar is connected to both circuits.

At a recent exhibition in Europe a direct-current generator rated at 12,000 amperes and 5 volts was shown.

The use of multiplex windings has, in general, been avoided due to the failure of these types to properly commutate in certain instances and to the uncertainty of satisfactory results. A paper has been presented calling attention to certain rules that must be observed when multiplex windings are used.

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Frequency Changer Sets

During the year a 40,000-kw. frequency changer set of the cascade induction motor type has been built and put into service and two sets of this capacity having both machines of the salient pole type are under construction, one of which is arranged with a spring support for the 25-cycle generator so that it may be used for single-phase power. A 7500-kv-a. set for converting from 60-cycles three-phase to 25-cycles single-phase is being built with the stator of the single-phase generator spring supported. The purpose of the spring support is to minimize the effect of the vibration incident to single-phase operation at low frequencies.

An automatic control equipment has been arranged to remove the field excitation of the motor and reduce that of the generator of a frequency changer set when a disturbance occurs on the motor circuit and again to restore the excitation when the line voltage is normal. This type of control called for a special design of the pole face winding to enable the motor to resynchronize while the generator is carrying part load at the reduced voltage. The benefit of this arrangement has been a greatly improved service due to a material reduction in the length of the interruptions.

Synchronous Condensers

Considerable advancement has been made recently in the design of synchronous condensers toward the reduction of losses. In sizes above 5000 kv-a., the losses are now as low as from 1.75 per cent to 2 per cent. The extension of high-tension distribution systems and higher transmission voltages has expanded the field of line voltage regulation by the use of synchronous condensers very rapidly. The largest condenser ever built, rated at 40,000-kv-a., 600 rev. per min., was recently put into operation in connection with a 220-kv. transmission line. The important consideration of keeping the losses down to a minimum has resulted in a strong tendency toward higher speeds. A considerable number of machines of 25,000 kv-a. to 40,000 kv-a. at 600 rev. per min. and of 15,000 kv-a. at 720 rev. per min. have been built. The disadvantage of the noise at these high speeds has been overcome largely by a totally enclosed construction.

An interesting development in the automatic control of synchronous condensers for line voltage regulation has been an installation of a 1000-kv-a. condenser provided with a voltage regulator arranged to start and stop on voltage indication. The condenser is at the end of a long transmission line and remains connected to the line through the starting tap in case of complete failure of power, thus providing a reactance for line protection when power is restored.

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Synchronous Motors

The past year has been marked by a further extended use of synchronous motors for many applications where induction motors have formerly been considered necessary. This extended use has been reflected in the development of complete lines of general purpose synchronous motors. The construction of a 9000-h. p., 6600-volt motor is of particular interest because of its application to the main roll of a steel mill and because it is the largest continuous rated motor of any type to be applied to industrial purposes. About 1½ per cent higher efficiency and the absence of about 4000 reactive kv-a. are the principal advantages obtained over a corresponding induction motor.

Another interesting development is a single-phase synchronous motor as part of a motor-generator set for use on heavy duty electric locomotives to supply direct current power to the main motors of the locomotives. These motors are rated 1200 kv-a.,

2300-volt, 25-cycle, single-phase for the freight locomotives, and 500 kv-a. for the smaller switching engines. These sets are brought up to about 80 per cent of synchronous speed by a starting motor of the repulsion type and then the motor is connected to the line at full voltage after which it quickly comes up to full speed and the excitation is automatically applied by a relay actuated by the current induced in the field during the starting period.

Induction Motors

No outstanding developments in the electrical design of general purpose induction motors have been brought out during the past year but the attention of designing engineers has been directed more particularly to the improvement of constructional features as relating to mechanical design and economical manufacture. A number of manufacturers have developed complete new lines with improved mechanical features.

The relative merits of sleeve and ball or roller bearings is a subject over which there is considerable discussion and difference of opinion. While a few manufacturers feature ball or roller bearings exclusively, the larger firms are prepared to supply either type according to the preference of the purchaser. New lines having tapered roller bearings have been developed which have overcome the assembly difficulties that previously made this type of bearing appear to be impractical for this application. General improvements have been made in the construction of the sleeve type of bearings to overcome the oil throwing and to exclude dirt and dust from entering the bearing which were objectionable features of the older design.

One manufacturer has adopted a fabricated construction of the mechanical parts of induction motors to the exclusion of cast parts except for the end bells. Another is using pressed steel end frames and riveted feet for moderate and small size motors. The motor manufacturers have in general retained the conventional casting construction for standard lines. General purpose motors having cast steel parts have been featured by one manufacturer while another has used the welded construction for large special motors.

Improvements in the power factor characteristics of induction motors have been accomplished by the adoption of more precise manufacturing methods. For instance, a grinding process has been adopted for finishing the stator and rotor cores of small machines to obtain uniformity of air gap. The use of larger bearings and shafts has permitted reductions of the air gaps resulting in better power factor. However, there is a strong conviction among designing engineers that better practise in application engineering presents the greatest possibilities for the improvement of power factor conditions in general power distribution systems. It is particularly important to avoid over-motoring, *i. e.*, installing motors of needlessly large capacity and operating them at low loads and consequently low power factor.

The ever extending use of electric power is presenting new and more severe conditions affecting the insulation of motor windings. Improvements in insulating materials and processes are being continually sought for the purpose of minimizing the destructive effects of dust, vibration, acid and alkaline vapors, and moisture. Form wound coils which are completely insulated before they are assembled in the slots present the least difficulties in that the interior of the coils can be completely filled with varnishes or compounds, but the so-called random wound coils in which the wires are not bonded together have presented a more difficult problem. A recent improvement in this type of winding has been obtained by encasing the complete end windings outside of the slots in a plastic insulating material.

During the year considerable attention has been given to theoretical studies of the performance characteristics of the synchronous induction motor and the compensated induction motor which combine the power factor characteristics of the synchronous motor with the starting torque characteristics of the wound rotor induction motor. For a number of years a type of synchronous induction motor arranged to receive its excitation from an external source has been in general use in Europe.

As mentioned in this committee's report of last year two new types of synchronous self-excited, induction motors have been developed in America. Another type of compensated motor has been developed this year in Europe which uses the Leblanc principle with one rotor having separate windings in separate slots. Although the use of the self-excited synchronous induction motor is being extended in America it has not reached anywhere near the proportions of the use of the separately-excited motor in Europe. American practise accepts the ordinary induction motor for general use supplemented by a relatively few synchronous machines for the purpose of maintaining good power factor conditions.

A European manufacturer is building a complete line of induction motors up to 225 h.p. with centrifugal-operated starters which have the same efficiency and power factor characteristics as the usual wound rotor type. This arrangement offers greater simplicity of starting than the ordinary manually operated compensator or controller. Compared with this the general practise in America has been to avoid the use of centrifugal devices and built-in resistances in polyphase motors. A recent European development has been a line of water cooled, totally enclosed motors primarily for pump drives. These motors are capable of being rated up to 70 per cent of the rating of the open type frame of the same size.

An interesting new development has been the design of a high-resistance squirrel-cage motor used largely for driving sugar centrifugal hydro extractors, etc.

The principal part of the load on this machine being the starting and stopping of a load of high inertia, it follows that the principal part of the losses in the motor are in the squirrel cage winding. The rotor of this motor has been designed with a high resistance section to the squirrel-cage winding which is built in the form of a fan to effectively dissipate the heat developed in the squirrel cage without communicating the heat to the rest of the motor.

A notable step in large size induction motors has been the building of a blooming mill motor having a continuous rating of 8000 h. p. at 13,200 volts. This is the largest continuous rating at the highest voltage yet obtained in induction motors.

Full voltage starting of induction motors is being urged by some engineers who claim for it greater efficiency, greater simplicity and lower cost, but there is a marked reluctance to abandon the time honored use of auto-transformers for reduced voltage starting. The so-called double squirrel-cage motors or those having high reactance rotor windings for full voltage starting or applications requiring high starting torque seem to be growing in popularity especially for high-speed ratings where the inherent reactance of the standard construction is low.

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HIGH-FREQUENCY MACHINES

During the past year a new development in high-frequency alternators has resulted from relatively new developments in the use of high-frequency power. The successful operation of air-core induction furnaces for melting copper, brass and nickel, and silver alloys has called for the development of generators suitable for supplying power at about 480 cycles for one type of furnace and at about 2000 cycles for another type. Current of 2000 cycles is also used for heating long objects of small sections such as boiler tubes. Generators for these purposes have been built in capacities up to 600 kw., single-phase, 480 cycles, and 150 kw., single-phase, 2000 cycles.. A further application of high-frequency power has been to obtan very high motor speeds for wood cutting and grinding operations and generators for three-phase power up to 420 cycles have been built for this purpose. These generators have been of the standard salient pole type, which is preferred to the inductor type because of the better characteristics. The high speeds and large number of poles has necessitated some special types of windings and mechanical details. A consideration of the fact that with a limiting peripheral velocity of 15,000 feet per minute the pole pitch of a 2000-cycle alternator is only ¾ inch will give some idea of the limitations of the field structure of such an alternator. The use of two-pole induction motors on frequencies of from 300 cycles to 420 cycles producing speeds of 18,000 rev. per min. to 25,000 rev. per min. has presented problems in motor construction more of the mechanical nature than of an electrical nature. The present limitation of speed is due to bearing troubles but the problem of the lubrication of high speed bearings is being studied with the hope that higher speeds can be used successfully if they are found desirable.

A recent European development for obtaining high motor speeds for wood working machinery consists of a combination motor having two stators and two rotors which are concentric. This motor develops a speed of 6000 rev. per min. on 50-cycle current. American practise has used the simpler high frequency motor supplied with power from frequency changer sets.

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SYNCHRONOUS CONVERTERS

Conditions in England have led to a careful study and development of motor-converters and apparent success has been obtained with a larger output per pole than has been obtained with d-c. machines in America. Ameri-

can practise has pinned its faith to the conventional six-phase synchronous converter. The largest capacity converter set that has been installed for heavy duty, 1500-volt, d-c. traction service was built during the past year and consists of two 1500-kw. rotary converters connected in series. Limitation of space available for the installation of a 4200-kw. synchronous converter led to a rather unique arrangement. It was desired that the transformer should be set on the base of the converter at the collector end. In order to make use of the space on both sides of the shaft, the transformer was split into two units each of half the total capacity and each connected six-phase and the converter was built with twelve collector rings for twelve-phase operation, taking advantage of higher efficiency, smaller space and lower cost. This is the largest twelve-phase converter of which we have knowledge.

An ingenious arrangement for obtaining a stepless voltage control of a direct-current power supply for crane motor operation has been devised by a European manufacturer which consists of a small three-phase synchronous converter which is direct connected to a self starting synchronous motor or booster. The stator of the booster is arranged so that it can be shifted angularly thereby varying the direct-current voltage of the converter from zero to plus or minus full voltage. The complete outfit is of small enough dimensions to be mounted in the crane cab.

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Induction Disk Phonograph Motor

Further applications of induction disk motors have recently been made to low-power, low-speed equipment. These motors operate under the same principles as used in the customary induction-type alternating-current watthour-meter. The rotor consists of a conductive disk, through which a shifting flux is produced by one or more split phase electromagnetic elements. Eddy currents are generated in the disk and the reaction between the eddy currents and the flux produces the driving torque.

The chief applications of induction disk motors heretofore have been as timing devices in demand meters, time switches, etc. However, a larger motor has now been perfected for phonograph drive and has been adopted by two of the most prominent phonograph producers. The chief advantages of this motor are silence, constant speed, lack of vibration and reliability. The rotor runs on a vertical shaft, the upper end of which also carries the phonograph turn table. No speed reducing gears are therefore necessary, the rotor turning at slow speed and driving the turn table directly. The motor has high starting torque, giving it rapid acceleration. The speed is controlled by a very sensitive fly-ball governor, operating through friction. The normal speed is 78 to 80 revolutions per minute, at which a torque of 6 inch ounces is produced, this being sufficient to drive any standard phonograph. The input to the motor is approximately 35 watts.

An important advantage of this electric phonograph motor over the spring motor lies in the fact that the former supplies a constant driving torque regardless of the length of time it is operated, whereas the spring motor delivers a varying torque. The torque of the spring motor starts at a rather high value just after it has been fully wound and tapers down to a low value as the spring unwinds.

The induction disk motor is desirable, of course, only for low power applications having a low efficiency. It is very reliable and silent, however, owing to its relatively slow speed and simple construction.

Induction Voltage Regulators

A new development in connection with induction voltage regulators has been the combination of a series transformer and a transfer switch with the regulator and so arranged that the polarity of the series transformer may be reversed thereby doubling the range of the regulator. The cycle of operation of the combination produces the same results as would be obtained by a regulator of twice the capacity. The switch is geared to the regulator which may be automatically operated. An outdoor type of regulator has been developed with all the auxiliaries including current and potential transformers mounted within the auxiliary casing. Induction regulators have been developed for use on 12,000-volt single-phase circuits. The noise of single-phase regulators has been materially reduced by the use of a cushion support for the regulator in its tank and a similar cushion between stator and rotor. An indicator has been developed to show the boosting or lowering position of the regulator rotor.

Mercury-Arc Rectifier

During the past year the mercury-arc rectifier has been further developed and notable improvements have been made particularly with regard to the automatic upkeep of the vacuum and to simplifying the control and auxiliary apparatus. This piece of apparatus would appear to approach the ideal for the rectification of alternating current in that the function is performed without transforming the energy into magnetic and mechanical energy with the attendant losses. The loss affecting the efficiency of the rectifier is the arc drop within the tank and since the arc drop is approximately constant the rectifier does not show as high efficiency at rated load as does the rotary converter for large low voltage capacities. For heavy duty traction purposes involving voltages above 600 volts

the rectifier has better efficiency characteristics. American manufacturers are now offering rectifier equipments for railway substations and industrial power uses that may operate in parallel with rotary converter or motor generator equipments and arranged for complete automatic operation. Rectifiers are usually supplied with a slightly dropping characteristic, which may be adjusted to match the characteristics of shunt wound rotary converters operating in parallel. Rectifiers may also be compounded in order to obtain voltage control; however, it must be appreciated that this control will slightly lower the over-all efficiency and power factor of the rectifier unit. Equipment has been developed to include the application of automatic voltage regulators for maintaining constant d-c. voltages. A peculiar advantage of the rectifier over other types of converters from a commercial point of view is that the rating of a unit is independent of the frequency of the alternating current and within certain limits a given rectifier is suitable for operation at various voltages, the kilowatt capacity being greater the greater the d-c. voltage. While rectifiers have been extensively used in Europe for more than one decade, there are only two commercial installations in America which have been in commercial service for more than one year. A few more were added during the past year, and a large number of equipments are on the books of American manufacturers and will go into service this year.

The voltage limitations of the rectifier are much higher than those of synchronous converters and motor-generator sets, for they are built in capacities as large as 3000 kw. at 4000 volts d-c. One 4000-volt plant has been in successful operation for more than two years on a standard gage railroad in Europe. These capacities are characterized by very high efficiencies. Since the loss is due only to the resistance drop of the arc the efficiency is inherently higher for the higher voltage ratings. Other advantages which have been claimed are that there is no synchronizing operation and there are no moving parts. The absence of noise and vibration makes the rectifier peculiarly desirable for substations in congested and residential districts where quiet operation is necessary. The successful operation of a rectifier depends upon maintaining almost a perfect vacuum and equipment is available which will accomplish this automatically. The operation of this equipment is based upon the principal that the transfer of heat from one body to another is accomplished by radiation and conduction but the conduction is dependent upon the gas pressure and is zero in an absolute vacuum. This device is called a hot wire vacuum gage.

The operation of rectifiers of this type is liable to be interrupted by an occasional arc-back which is a short-circuit between anodes and occurs when one or more anodes function temporarily as a cathode. Since this occurrence causes no damage to the equipment except in very rare cases, the rectifiers may immediately be restarted by reclosing the breakers either manually or automatically. The cause of arcing back is being studied and it is hoped that this difficulty will be overcome.

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I wish in conclusion to express my appreciation of the assistance of Messrs. W. J. Foster, R. B. Williamson, V. Karapetoff, V. M. Mountsinger and others, in the preparation of this report.

STEAM POWER VS. WATER POWER

Is steam power to outdistance water power for generating electric current in the Pacific Coast country where "white coal" is king? This tendency is noted by the Journal of Electricity in an editorial declaring that cheapness of oil fuel and 300-per cent advances in the efficiencies of steam generating machinery during the past decade indicate that steam power may prove the more economical even in the water-powered state of California. Only one-third of the electric energy used in the state is generated by steam today, while hydroelectric plants produce the balance but engineers are prophesying the ratio may soon be reversed.

"A majority of the hydro power sites have been or are being developed," says the editorial, setting forth the facts of the case. "Efficiencies of 85 to 90 per cent of the theoretical have been obtained in waterwheels and there is little opportunity for improvement here. A cycle of comparatively dry years has placed added emphasis on steam plants.

"Many of the western states abound in low-grade coal which can be utilized either in pulverized form, as has been done successfully in Washington and Colorado, or can be subjected to low temperature distillation and burned in the form of coke and gas. Even California has extensive fields of lignite, and transportation facilities are such that cheap coal can be brought from Utah, Arizona, New Mexico or Washington. Whether steam will supplant hydro in supremacy is a debatable subject but certainly conditions point to a decided swing of the pendulum toward steam."

Notes on the Vibration of Transmission-Line Conductors

BY THEODORE VARNEY[1]
Associate, A. I. E. E.

***Synopsis.**—This paper describes tests made with a graphic recorder to show the vibration of transmission-line conductors under various conditions of wind velocity, conductor tension and span length. The method of taking the records is discussed. Formulas are given for determining the velocity of propagation of transverse waves along a conductor, the wave length of a vibration, and the frequency of vibrations caused by "eddies" formed at a conductor subjected to air currents.*

If a wire is suspended freely between supports and is struck near one of the supports, a wave will run along the wire to the other support, be reflected and return to the starting point. If the supports are rigid, that is, possessed of infinite mass, the wave will be entirely reflected and it will pass back and forth until the viscosity of the wire damps out the wave. With a decrease in the mass of the support, the amount of the wave energy reflected is lessened. Part of the energy passes into the support, either storing energy therein to be given back to the latter if the support is elastic, or becoming dissipated by the viscosity of the support.

Assuming that the tension in the wire is constant, the velocity of propagation of the transverse wave is:

$$v = \sqrt{\frac{P}{m}} = \sqrt{\frac{P\,g}{w}} \qquad (1)$$

When

v = Velocity in feet per second
P = Total tension in the wire
m = Mass per ft. of wire
w = Weight per ft. of wire in pounds
g = Acceleration due to gravity

The time required for the wave to travel twice the length of the span is the fundamental time period. If at the instant the first impulse reaches the starting point the wire is struck again, the vibration will be sustained. If at the instant the impulse reaches the second support the cable is struck again, the two crests meet at the center, producing a node. If the frequency of the exciting force is increased, the span breaks up into a series of nodes and loops. If resonance occurs, there must be a whole number of loops between supports, provided the mass of the wire is uniform.

The velocity remaining the same, the product of wave length and frequency is a constant and is equal to the velocity; that is,

$$l\,f = v \qquad (2)$$

Where

l = Twice the distance between nodes
f = Frequency in cycles per second

In cases where resonant vibration of conductors has been observed, it was traceable usually to the wind blowing across the line and always at low velocities. A strong wind broke up the resonant conditions and merely swayed the span as a whole. The vibrations were in a vertical plane. Resonance appeared more frequently in the early morning or near sundown. Resonance also occurred over a wide range of cable tensions.

Resonance in a transmission cable is a very elusive thing; it begins without warning and ceases abruptly, and, while the conditions at the moment as regards temperature, wind velocity and direction may be noted, it is impossible to maintain or reproduce them at will.

It was at first thought that a span vibrating with fixed nodes and loops would not be affected by moving the point of support to the first node. If this were true, then the behavior of a single loop could be investigated on a small scale, experimentally, and would afford means of observing the behavior of a full sized span. Accordingly, an attempt was made with several sizes of stranded cables to produce resonant vibration by mounting the cable transversely in an aviation wind tunnel. The tunnel used was 8 ft. square and the wind could be varied from zero to 75 mi. per hour. The cables were supported at the sides of the tunnel and the tension in the cable was varied over a wide range.

No resonant vibrations could be produced. The cables vibrated rapidly with a very small amplitude, not over one one-hundredth or two one-hundredths of an inch. These small vibrations were noted by means of a reflecting mirror and a stroboscope and were found to agree fairly well with the eddy frequency.

The meaning of the expression "eddy frequency" will be explained later.

The probable reason why resonance and considerable amplitudes could not be obtained in the wind tunnel is that it is difficult to maintain constant wind velocities over the whole length of span. Moreover, upon further thought, it is more difficult to maintain approximately resonant conditions over a short span than it is over a long one. If, to assume an example, the wind velocity were adjusted so as to produce one loop in an 8-ft. span, it would require a change in wind velocity of 100 per cent to create the next larger whole number of loops, that is two, in the span. Any intermediate value of wind velocity would not produce resonance. If, on the other hand, the span were 80 ft., a 10 per cent change

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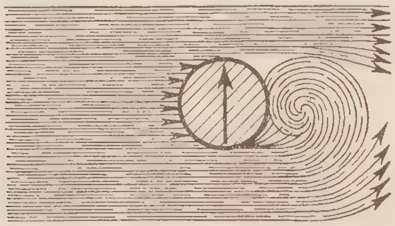
1. Aluminum Company of America, Pittsburgh, Pa.
Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

in velocity would be necessary to produce either nine or eleven loops in the span, while in a span 800 ft. long, only 1 per cent change would be necessary to produce 99 or 101 loops in the span.

In actual long spans of transmission lines, the nodes have been observed to shift back and forth in position with the slight changes in wind velocity, the vibrations, however, persisting with considerable amplitude for long periods of time.

In 1921 an investigation made by E. F. Relf and E.



Eddy Formation Produced by Wind Blowing on a Wire

Ower and covered by a report to the British Aeronautical Research Committee, showed that the singing note produced by wires moving rapidly through the air corresponded with the periodic eddies produced behind the wire.

When a fluid medium, such as air or water, flows past an obstruction in its path, eddies are produced behind the obstruction. If the obstruction is of symmetrical cross section such as a circle, the behavior of the eddies formed will be similar upon each side of the obstruction. As the fluid flows past the obstruction, the friction on the two sides is not exactly the same at any particular instant and this tends to slightly lower the velocity of the fluid passing on one side. The fluid on the other side, continuing in its normal velocity, creates a slight difference of pressure back of the obstruction, the lower pressure area being on the side where the higher velocity exists. This causes a flow of the fluid from the opposite side to fill this rarified area, and the action of the fluid takes the form of swirls or eddies. As this rarified area is restored to normal density by the inflow of the eddy, the velocity on that side of the wire is reduced and the inrush of the eddy accelerates the motion of the fluid on the other side and presently the eddy ceases on the first side and begins on the other, thereby repeating the cycle of events.

The result of this alternating-eddy formation is to produce an alternating force on the obstruction in a plane at right angles to the flow of the fluid. In aircraft work, the obvious means to prevent the formation of these eddies is to "stream-line" the section of the obstruction, thereby allowing the air to flow down both sides and join at the rear edge of the section without the formation of these eddies. The figure shown herewith illustrates this eddy phenomenon.

Experiments in both air and water were carried out from which the truth of the following general expression was established:

$$f = \frac{V}{D} \text{ function} \left(\frac{V\,D}{e} \right) \tag{3}$$

Where

f = Frequency in cycles per sec.

V = Velocity of the medium with respect to the cylindrical wire

D = Diameter of the wire

e = Coefficient depending upon the medium, being 0.000159 for air and 0.0000122 for water

Further investigations gave the following data; When

$$\frac{V\,D}{e} = 100, \text{ function} \left(\frac{V\,D}{e}\right) \text{ equals } 0.125$$

$$\frac{V\,D}{e} = 150, \text{ function} \left(\frac{V\,D}{e}\right) \text{ equals } 0.150$$

$$\frac{V\,D}{e} = 300, \text{ function} \left(\frac{V\,D}{e}\right) \text{ equals } 0.172$$

$$\frac{V\,D}{e} = 600, \text{ function} \left(\frac{V\,D}{e}\right) \text{ equals } 0.185$$

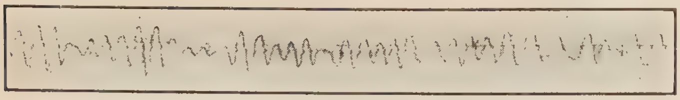
When

$$\frac{V\,D}{e} \text{ is greater than 600, function} \left(\frac{V\,D}{e}\right) \text{ equals } 0.185$$

It will be noticed from the foregoing that function $\left(\frac{V\,D}{e}\right)$ is a constant for values of $\frac{V\,D}{e}$ of 600 or greater. For a wind velocity of one mile per hour, the minimum value of D would be 0.78 in. For two miles per hour the minimum value of D would be 0.39 in. Therefore for usual transmission line conditions, a constant value for the function $\left(\frac{V\,D}{e}\right)$ can be used. Curves of frequency plotted against wind velocity become, therefore, a series of straight lines—one for each diameter of conductor.

As a check upon the application of this theory, the following results tabulated from a long series of painstaking observations upon a certain transmission line are of interest. The cable in this case was 1 in. diameter, weighing 0.858 lb. per ft. and was supported upon steel towers.

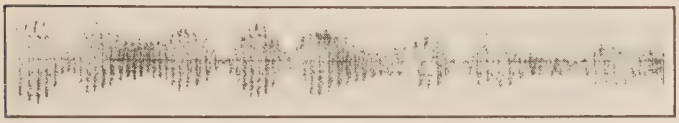
The accompanying charts were obtained by attaching one end of a string to a transmission wire and the other end to a light wooden block arranged to slide in a slot in a vertical board which was fastened to a board resting on the ground. The lower end of this block had attached to it a light spring which served to keep the string taut and yet permitted the block, with the pencil attached, to move up and down in response to the



No. 1—Length: 4 seconds

No. 2—Length: 4 seconds

No. 3—Length: 7 seconds



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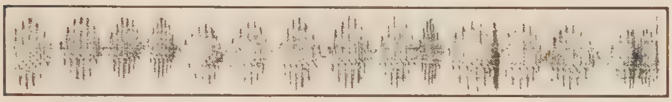

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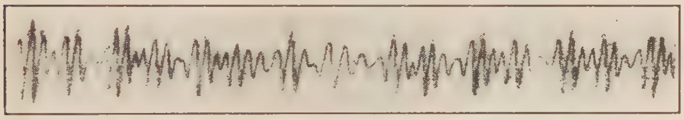

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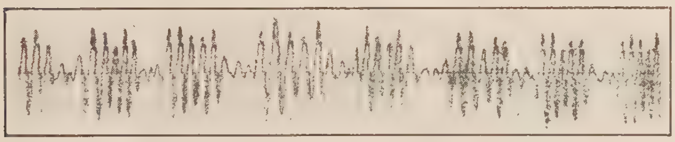
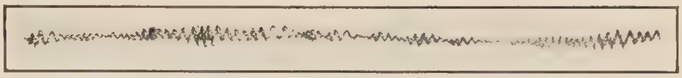


No. 7—Length: 3 seconds

No. 8—Length: 7 seconds



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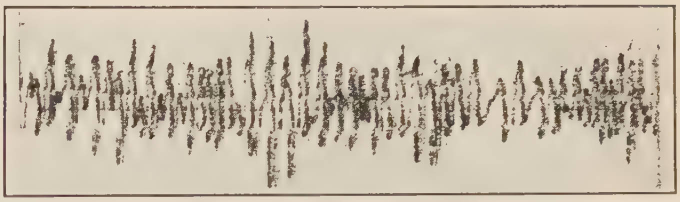

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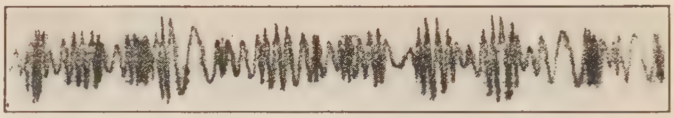
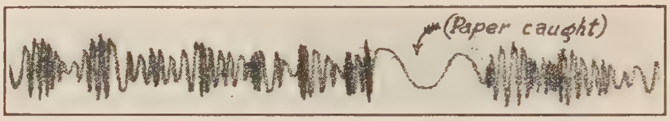
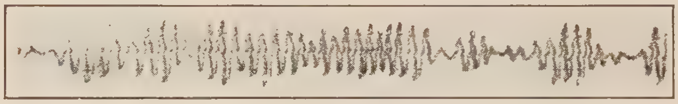


No. 11—Length: 7 seconds



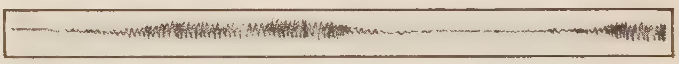
No. 12—Length: 6 seconds



No. 13—Length: 4 seconds

No. 14—Length: 4 seconds

No. 15—Length: 7 seconds



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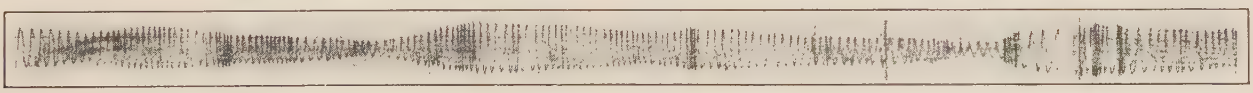

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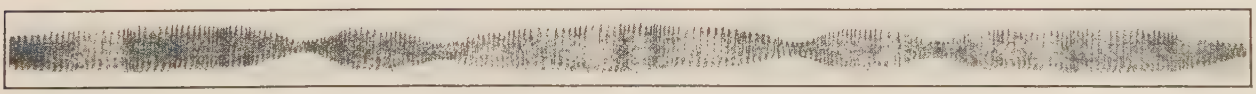
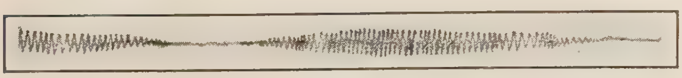
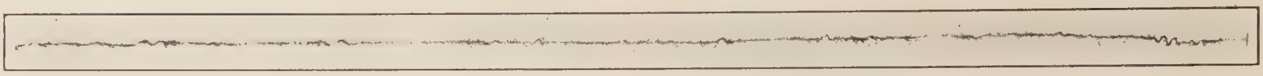


No. 18—Length: 11 seconds

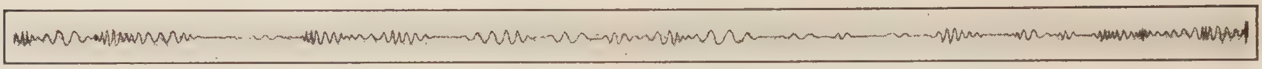


No. 19—Length: 6 seconds

Records of Transmission-Line Vibrations
(See table for detailed information)



No. 20—Length: 8 seconds



No. 21—Length: 8 seconds

No. 22—Length: 8 seconds

No. 23—Length: 5 seconds

RECORDS OF VIBRATION OF TRANSMISSION-LINE CONDUCTORS
(See table for detailed information)

DATA RECORDED IN VIBRATION TESTS ON TRANSMISSION LINES

The conductor upon which the tests were made was 1 in. in diameter, weighed 0.858 lb. per ft. and was supported upon steel towers.

1	2	3	4	5	6	7	8	9
Chart No.	Span (ft.)	Tension (lb.)	Wave Velocity (ft. per sec. calculated)	Wind Velocity (M. P. H., Measured)	Eddy Frequency (cy. per sec. calculated)	Vibration Frequency Recorded on chart (cycle per sec.)	Amplitude of Vibrations Recorded on chart (1/32 inches)	Loop Length (ft.)
1	1200	8500	565	5.2	17.0	9.5	12	29.7
2	"	"	"	7.7	25.0	12.5	28	22.6
3	"	"	"	8.0	26.0	12.5	26	22.6
4	"	"	"	8.5	27.5	21.5	22	12.8
5	"	"	"	8.9	29.0	18.3	24	15.4
6	"	"	"	10.0	32.8	18.3	12	15.4
7	"	"	"	11.0	36.0	20.0	16	13.2
8	"	7930	545	10.0	32.8	33.0	4	8.3
9	"	7700	538	3.5	11.5	13.0	12	20.5
10	"	7530	532	3.9	12.8	14.0	24	19.2
11	"	"	"	4.8	16.0	11.3	18	23.4
12	"	"	"	5.2	17.2	10.5	14	25.7
13	"	"	"	5.6	18.7	12.0	20	22.5
14	"	"	"	7.8	25.5	22.0	12	12.2
15	"	"	"	8.0	26.0	22.0	6	12.1
16	"	"	"	19.1	62.5	23.0	6	11.6
17	"	"	"	21.3	69.5	22.0	18	12.3
18	"	"	"	21.3	69.5	22.0	20	12.3
19	"	"	"	22.5	73.0	22.5	8	11.8
20	984	5600	460	3.40	11.0	14.0	2	16.4
21	"	"	"	5.00	15.0	15.0	6	15.3
22	"	"	"	5.70	19.0	15.0	6	15.3
23	"	"	"	5.90	20.0	20.0	1	11.5

vibrations of the transmission-line wire. The spring was attached as nearly as possible at the middle point of the first node from the insulator clamp.

A wooden slide with a strip of paper attached to it was then moved in a direction at right angles to the movement of the pencil and was timed with a stop-watch. The device was crude but the charts afford a means of determining quite accurately the total number of vibrations produced in a certain time.

In the cases described herein the cable was quite large and the vibration had sufficient force so that the string could be pulled quite taut without damping the vibrations. This prevented, to a considerable extent, interference due to the fluttering of the string by the wind.

In other cases where the wire was smaller and the fluttering of the string interfered with proper results, a temporary platform was erected on the tower and by cutting off the current on the line, some charts have been obtained by attaching a pencil directly to the wire. The first described method has the advantage that it can be used on a live line and charts can be made on short notice, whenever the wind conditions are observed to be favorable, without taking time to cut the power off the line and arranging for a series of observations. However, as noted, it is very often difficult to

obtain satisfactory results by this means in the case of small line wire. The amplitudes of the vibrations are obtained by measuring the charts directly.

In the tabulations given herewith, the figures in column 1 refer to the number of the charts as appearing on the reproduction of the charts themselves. The second column gives the length of span where these particular charts and observations were made. In this case, the supports were practically level. It will be noted that the observations are made upon two-span lengths. The third column gives the total tension in pounds in the span at the time of the observations. These tensions were calculated from the observed sags. The fourth column gives the theoretical velocity of propagation of transverse waves in the cable as described in equation (**1**).

Column 5 gives the wind velocity in miles per hour as noted by a portable anemometer used during the experiments. Column 6 gives the theoretical eddy frequency calculated from the size of wire and observed wind velocity, using equation (**3**). In equation (**3**) the values of V and D must be in the same units; that is, V is feet per second and D is diameter in feet of the conductor. Also, these units might be used in terms of inches per second and inches of diameter.

Column 7 gives the frequency in cycles per second as taken directly from the charts. Column 8 gives the amplitude also measured directly from the chart. Column 9 is the calculated loop length using equation (**2**). The values of V in this equation are taken from column four and the values of F are taken from column 7. The values in column 9 obtained by this means are, therefore, theoretical but they check with a fair degree of accuracy with the actual observed distances between nodes at the time of the observations.

On account of the variable character of the wind under most conditions, however, these node points were observed to shift constantly back and forth. Usually, however, they corresponded to values sometimes smaller and sometimes greater than the loop length given in column 9. It is assumed, therefore, that the theoretical values given in column 9 are fair assumptions.

Chart 8 is particularly interesting because of the absence of "beats" and the exact agreement between the eddy and observed frequency. This is interpreted as indicating a practically uniform wind velocity throughout the entire span. It is likely also that the time period of oscillation of the tower supports acts to amplify or damp the line vibration.

A device at the support which has a period corresponding to a certain proportion of the natural period of the conductor will act as a damper. Such a damper having a period of about seven cycles per second would probably be effective in greatly reducing the amplitude of vibrations in the conductor throughout the range of wind velocities noted in the case described herein.

It is reported that the device recently described in the technical press[2] by Mr. G. H. Stockbridge, of Los Angeles, California, has been found effective. Further investigations on transmission lines in service are at present going on.

The writer is indebted for various courtesies and assistance in obtaining the data described in these notes from Capt. Wm. McEntee and Dr. A. F. Zahm of the United States Navy Yard, Washington, D. C.; Mr. H. A. Barre and Mr. H. Michener of the Southern California Edison Co., Los Angeles, Calif; Mr. A. E. Silver, Electrical Engineer, Electric Bond & Share Company, New York and to Messrs. M. E. Noyes, J. P. King, Walter Hays and C. B. Owen, Aluminum Company of America.

HYDROELECTRIC DEVELOPMENT IN FRANCE RETARDED

France has water-power resources which, under satisfactory conditions, are capable of producing the electric energy necessary for its economic advancement. A serious effort has been made to utilize these valuable natural resources, but unfavorable conditions for some years have impeded such efforts, and recent statistics on electric development show a marked decrease as compared with expected results. Although construction works begun during or subsequent to 1916 have been steadily continued and improvements have been made to the installations already in use, the carrying out of the greater part of new projects, for which plans were completed at the beginning of 1924, have been indefinitely postponed.

The average amount of current supplied by French hydroelectric plants during the period 1922 to 1924, inclusive, increased from 658,560 to 1,263,260 kilowatts, but the increase registered for 1925 was only about 50,000 kilowatts, and even this greatly slackened rate will probably not be maintained in 1926. This stagnation is not caused by decreased demand for additional current, for consumption of electric current steadily increases. During the past year there has been a tendency to meet this demand by the enlarging or erection of fuel power plants rather than by the installation of hydroelectric plants. The result is that three-fourths of the electric current furnished to consumers in France by the entire system of electric distributing stations is supplied by fuel power plants.

Lack of finance is the chief cause of this condition. The Government has made a careful survey of the electric power resources and has reached the conclusion that systematic construction and installation should be inaugurated and future development promoted. Special legislation and financial enactments are now pending which are intended to rectify the present situation by providing sources of revenue and foundations for loans.

2. *Electrical World*, December 26, 1925, p. 1304.

Some Notes on Electricity Transmission and Distribution Practise in Europe with Comments on High-Tension Substations and Switchgear

BY G. F. CHELLIS[1]
Member, A. I. E. E.

Synopsis.—*This paper describes some of the more recent overhead and underground electricity transmission developments in Europe and is intended to convey a general idea of the status of that art in some of the European countries.*

No attempt has been made to include all the recent high-tension lines in the countries touched upon, but those included are typical of the work being done and the voltages in use.

A most interesting part of the paper is a summary and analysis of the recent report of the Weir Commission of England recommending a policy with regard to superpower development in that country. This report covers a program extending to 1940 and proposes a plan of interconnection and base-load plant construction intended to tie together practically all parts of England.

* * * * *

General

A CONSIDERABLE amount of electrical plant construction has been going on in Europe during the last five years to meet increases in power demand, resulting principally from industrial growth.

Water-power has been developed wherever possible, but regardless of high fuel cost and uncertainty as to fuel supply, steam plants have been necessary in certain areas.

Recent statistics indicate that the electricity consumption per capita in some of the European countries is higher than in the United States, but such statistics are confusing and do not present a true picture of electrical progress, except where industrial and domestic consumption are separately shown. This point is clearly brought out by considering the total unit consumption in certain mining and industrial communities where it amounts to 50,000 watts or more per capita, but with relatively low domestic consumption.

A good deal of work must be done to educate the public to a greater use of electrical energy, and growth of domestic load in Europe should, therefore, be slower than in American communities which are being energetically exploited.

Although there are wide variations in climatic and topographical conditions, government regulations, and engineering points of view in Europe, there seems to have been produced in the different countries, types of line construction well suited to local conditions.

There is considerable diversity in the design of transmission line supports which, in general, are somewhat more flexible than the usual American designs; while spans are shorter, with relatively higher safety factors in conductors.

Sweden

As the distances over which power has to be transmitted in the European countries are relatively shorter, such extensive transmission line networks as those which have been developed in the United States, and Canada, are not found.

The Swedish State Lines, planned by the Royal Board of Water Falls, are perhaps an exception to this general statement, as these lines form the nucleus of an extensive future superpower system designed to work at

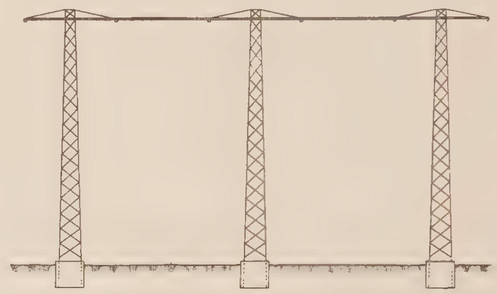


Fig. 1—Type of Standard Steel Support for Two 200-Kv., Three-Phase Circuits

(Trollhattan-Vasteras Line of Swedish State Power System)

Height of support above ground	52.5 ft. (16 m.) approx.
Distance between mast centers	39.4 ft. (12 m.)
Conductor spacing	19.7 ft. (6 m.)

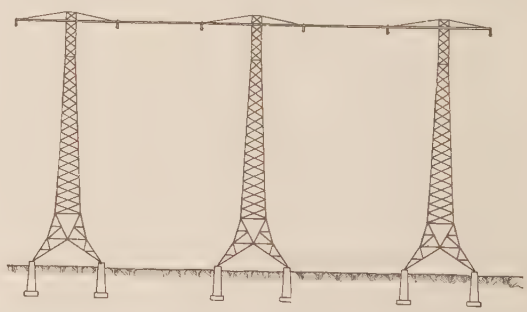


Fig. 2—Type of Steel Anchor Structuref or Two 220-Kv., Three-Phase Circuits

(Trollhattan-Vasteras Line of Swedish State Power System)

Height of support above ground	52.5 ft. (16 m.) approx.
Distance between mast centers	39.4 ft. (12 m.)
Conductor spacing	19.7 ft. (6 m.)

1. Whitehall Securities Corporation, Ltd., London, England.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

220 kv.; but those built to date will be operated at a reduced voltage until the higher voltage is required.

Two types of towers used in the construction of the Western Trunk Line of the Swedish State System between Trollhattan and Vasteras are shown in Figs. 1 and 2.

Italy

Italy shares with Switzerland the run-off from the Swiss-Italian Alps, which provides an abundant source of water-power, and here, as well as in Switzerland, rapid progress has been made in hydroelectric development and transmission lines.

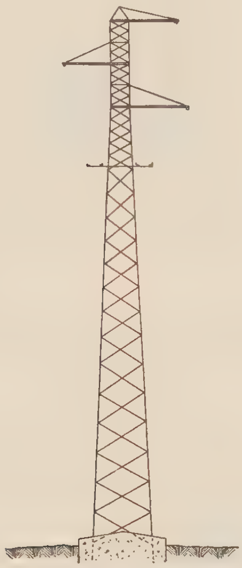


Fig. 3—Type of Standard Steel Tower for One 125-Kv., Three-Phase Circuit

(Temu-Cedegolo Line of the Soc. Gen. Elletta dell 'Adamello)

Fig. 4—Type of Standard Steel Tower for One 130-Kv., Three-Phase Circuit

(Reggio-Emilia Line of the Soc. Eletta. Interreguiale Cisalpina)

Height to lowest cross arm	69 ft. (21 m.)
Average span	820 ft. (250 m.)
Conductor spacing	17.5 ft. (5.3 m.)
Weight of tower	4800 lb. (2200 kilos)

Because of the rugged topography of Northern Italy, transmission lines must be largely confined to the narrow valleys, in some of which there are as many as ten parallel multicircuit lines of voltages ranging from 2-kv. to 130-kv.

Fig. 5—Type of Standard Steel Tower for One 140-Kv., Three-Phase Circuit

(Ovesca-Arquata Line of the Soc. Gen. Italiana "Edison di Eletta" Milan)

Average span 656 ft. (200 m.)

The types of tower used on three of the more interesting lines recently built in Italy are shown in Figs. 3, 4, and 5.

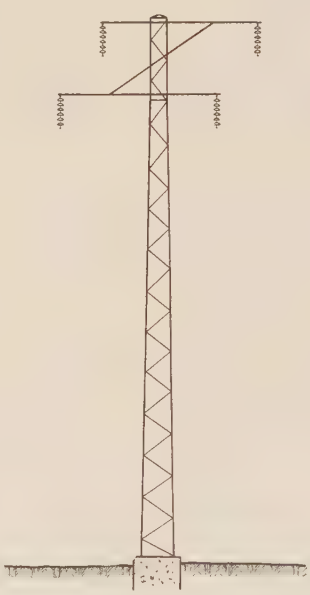


Fig. 6—Type of Standard Steel Tower for One 135-Kv., Three-Phase, 50-Cycle Circuit and Four 66-Kv., Single-Phase 16-2/3-Cycle Circuits

(Amsteg-Immensee Line of the Swiss Federal Railways)

Length of line 29 mi. (47 km.)
Average span 787 ft. (240 m.)
Maximum span 1610 ft. (490 m.) with 620 ft. (190 m.) difference in elevation of supports
Conductors aluminum steel reinforced except bronze on long spans
Ground wire galvanized steel

Switzerland

The most important recently constructed transmission lines in Switzerland have been built by the

Swiss Federal Railways, in conjunction with the electrification of that system. Certain of these lines are jointly owned by the Federal Railways and the Swiss Power Transmission Co., Ltd., of Berne.

These lines are of interest on account of the high single-phase voltages employed, which are 66 kv. and 132 kv.

The types of standard tower used on three of these lines are shown in Figs. 6, 7, and 8.

Fig. 7—Type of Standard Steel Tower for Two 132-Kv., 16-2/3-Cycle, Single-Phase Circuits

Length of line	134 mi. (216 km.)
Height to lowest conductor	28 ft. (8.5 m.)
Average span	737 ft. (216 m.)

Conductors aluminum steel reinforced.
Insulators, suspension type, seven units.
Ground wire, copper clad steel.

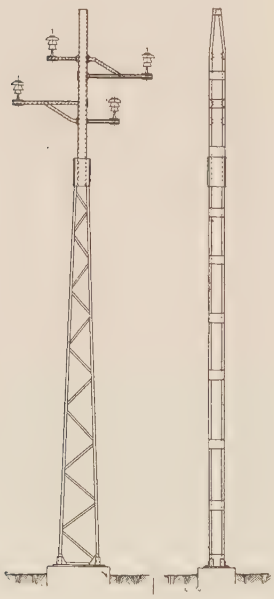


Fig. 8—Type of Steel Tower Used on Standard Transmission Lines for Two 66-Kv., Single-Phase, 16-2/3-Cycle Circuits

(Swiss Federal Railways)

Length constructed, 155 mi. (250 km.)
Average span, 410 ft. (125 m.)
Conductors, stranded copper
Ground wire, galvanized steel

Spain

Concrete poles, Fig. 9, with concrete cross-arms cast integral are used on the 70-kv. lines of the Cia Anonima Mengemor, Spain.

A photograph of one of the anchor towers of the 130-kv.

Fig. 9—Type of Concrete Line Support on 70-Kv. Lines of Cia Anonima Mengemor, Spain

Average span 328 ft. (100 m.)

Albaseta - Dos Aquas line of the Sociedad Anonima Hidroelectrica Espanola is shown in Fig. 10.

Germany

The 100-kv. Lauta-Trattendorf line in Germany is worthy of serious consideration as a precedent in the construction of high-tension lines on public highways.

Fig. 10—Type of Steel Anchor Tower on 130-Kv. Albaseta-Dos Aquas Line of the Sociedad Anonima Hydroelectrica Esponola

Average span 656 ft. (200 m.)

While few municipal authorities would sanction the construction of lines of such voltages in the public street, the factor of safety is no doubt higher than that common to overhead contact wires for tramway systems.

A typical view of this line is shown in Fig. 11.

England

In England, with the exception of one group of companies in the North, which operates about 1000 mi. of high-tension lines, extensive overhead transmission

systems have not been developed. This is perhaps due to the wide distribution of its coal deposits which renders transmission less effective than in places where power markets are widely separated from sources of fuel.

A further explanation of the relatively few overhead lines constructed in England is to be found in the well-established practise of placing power lines underground, which has to a large extent been forced by strict Government and Municipal regulations, and by the difficulty and delay experienced in securing suitable rights of way.

Numerous attempts have been made in England to establish a policy with regard to national superpower developments, beginning as early as 1914. The principal schemes have been included in reports made in 1918 by the Electric Power Supply Committee (known as "The Williamson Report") and the report of the Commission appointed by the Minister of Transport

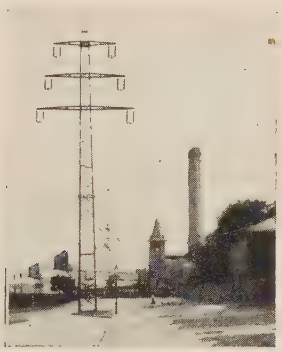


Fig. 11—Type of Steel Support on 100-Kv. Lauta-Trattendorf-Moabit Line in Germany

Height of tower, 92 ft. (28 m.)
Height to lowest crossarm 65 ft. (19.8 m.)
Conductor spacing (3.1 m.)
Conductors—copper
Insulators, two strings of six Kapp units
Minimum clearance between line and buildings (26 m.)

to review the national problem of the supply of electric energy (known as The Weir Report) which was published early in the year 1926.

The scope of the report covers a period to the year 1940 when the consumption in Great Britain, now growing at the rate of 19 per cent per annum, would be raised from the present figure of 110 units per capita to 500 units, the rate now obtaining in the United States; but it is expected that the 500-unit figure may be reached before that date.

The basic recommendations of the Committee are as follows:

a. To reduce to 58 in number 438 of the power stations in Great Britain, many of which are small and unsuited to generate power economically. The 58 stations, 28 of which would be of capital order and 30 of secondary order, would be designed to produce electrical energy at a minimum cost. (These 438 stations do not include 48 stations owned by railway companies, and operated particularly for railway electrification.)

b. To establish a gridiron (high-tension transmission network) for the purposes of interconnecting the 58 power stations.

c. Provision for the output of the 58 power stations to be turned into the gridiron at a predetermined price per unit with privilege of purchasing for local supply, at the price billed to the gridiron.

d. Provision for the closing down of nearly 400 generating plants which is expected to be brought about automatically as the companies operating them would be able to purchase power from the gridiron at a cost less than that of private generation.

e. Provision for the establishment in communities, not at present supplied with electricity, for local authorities, who would distribute power purchased from the gridiron in such areas.

f. Recommendations in favor of the standardization of frequency affecting a few of the larger suppliers. Subject to further investigations this may be undertaken at public expense at a total gross cost approximately £10,500,000, and a net cost of £8,000,000 after allowing for expenditure represented by useful additions to plant capacity.

It is estimated that the total expenditure to 1940 would extend upward to £250,000,000 and that with proper coordination and assistance from the Government, this figure is substantially less than would result if developments were allowed to continue under existing conditions.

It is further estimated that one-half of this amount of new money would be required in connection with the development of distribution systems, this portion of capital to be provided by local authorities, power or distribution companies, as at present.

It is stated that the remaining half of the capital can be conveniently divided into two sections:

First. The amount necessary to construct the high-tension network for bulk transmission, plus working capital, reserve, and interest capitalized for a period of five years, at which date the net earnings from the gridiron would be expected to be sufficient to cover all obligations.

It is estimated that the sum of £25,000,000 would be required for gridiron expenditure at the end of five years from the date the scheme might be put into operation.

Second. The amount necessary to provide local authorities, or other authorized persons with capital required for the erection of new capital generating stations, or additions to present stations. Within certain limits capital and interest would be guaranteed by the Government.

The report points out the following conditions obtaining in Great Britain at the time of its issue.

Average price charged to consumers for all purposes	2.047d. (pence)
Gross revenue	£34,256,000
Revenue per £100 invested	£21.2
Plant installed	3,096,535 kw.
Maximum load	1,844,000 kw.
Spare plant	68 per cent of maximum load
Units sold per annum	4,016,000,000
Units sold per head of population	110
Annual load factor	24.9 per cent
Capital invested per kw. for Generation	£23.8
Capital invested per kw. for distribution	£28.5
Total capital investment per kw. for generation and distribution	£52.3

It is estimated that as a result of economies to be effected by the recommendations of the committee, the position in the year 1940, or whenever the national consumption has been raised to 500 units per head, would approximate the following:

Units sold per capita	500
Maximum load	8,135,000 kw.
Kw. installed	10,000,000 kw.
Spare plant	25 per cent
Units sold	21,385,000,000 (kw-hr.)
Annual load factor	30 per cent
Total capital invested for generation	£127,000,000
Capital invested for "Grid Iron" transmission	£29,000,000
Capital invested for distribution	£243,500,000
Total revenue	£88,100,000
Average price per unit	1 d. (pence) or under
Number of capital stations	28
Number of secondary stations	30
Total number of stations	58

In the annex to Appendix I of the report there appears an interesting estimate of the cost of power stations of 133,000-kw. installed capacity, capable of meeting maximum load conditions of 100,000 kw., which is said to be based on contracts for the Barking Station of the County of London Electric Supply Co., Ltd., one of the principal superpower stations constructed in England to date.

	£ per kw.
308 acres of ground at Barking	0.733
Civil engineering works, piling, wharfs, railway sidings, water culverts, screens and foundations	1.880
Buildings and cranes	1.722
Turbo alternators and accessories	3.950
Boilers and accessories, and ash-removal plant	3.464
Switchgear and cables	0.683
Step-up transformers and station auxiliaries	0.593
Piping	0.465
Coal-storage equipment, consisting of cranes, locomotives, and cars	0.148
Sundries, including batteries and charging sets, oil coolers and pumps, oil filter plant, auxiliary sets and wiring and fittings	0.301
	£13.939
Engineering supervision, legal and incidental expenditure (5 per cent)	0.697
	£14.636

It is estimated that the average total cost of generation per kw. on the basis of coal at 16s. (shilling) per ton would be 0.3456d. (pence) with an additional capital and operating charge on main transmission lines of 0.0291d. (pence) or a total of 0.3747d. (pence) per unit sold over the gridiron.

Local distribution expenditure, including capital charges, local management and taxes, is further taken at 0.5000d. or 0.8747d. per unit at the distribution system, which is raised to 1.029d. on the basis of 85 per cent distribution efficiency.

It is understood that the assumed efficiency of 85 per cent has caused some amount of criticism.

According to the report the average cost of 1d. per unit would not be a uniform price maintained throughout Great Britain, but would vary according to local generating conditions, the amount of transmission network involved, and the distribution expense.

The estimated figure for Scotland is given as 1.038d. per unit, and that for Central England as 1.029d. per unit.

A striking feature of the report is a recommendation that the transmission network be owned and controlled by a new body created by Act of Parliament, termed the Central Electricity Board, which would purchase and dispose of energy from all of the interconnected stations, or alternatively charge for the use of the transmission network, or a further alternative according to which all generating stations would be purchased and the less efficient ones closed down, leaving the best stations to be operated by the Board, thus bringing all generation and transmission under the control of a single body.

Objection has been raised in some quarters on the ground that acceptance of the latter recommendations might be a step toward government ownership. On this account an opposition movement is on foot to prevent the bill being passed by Parliament.

The report is noteworthy as constituting the largest scheme ever proposed for the unification and extension of electric service for the definite purpose of reducing the cost of electric energy to a community.

In general, the measure seems to be popular, and there is every indication that some such Bill will be authorized by Parliament in the near future as it appears to be agreed that only through the intervention of Government interest can such a system be brought into being on account of the great diversity of interests involved.

The report shows typical curves of load and load factor, but no maps or other data are included to show details of the interconnecting network.

A transmission voltage of 33 kv. seems to be considered sufficiently high for average English conditions, at present, and has been more or less standardized for both overhead and underground lines. Some 66-kv. lines have been built and still higher voltages will no doubt be employed if extensive electrification plans are adopted.

Typical views of some of the high-tension trans-

mission lines recently constructed in England are shown in Figs. 12, 13 and 14.

Fig. 15 shows the dead-end structure of a 66-kv. line and its junction with 66-kv., single-conductor cables leading to the transformers.

Fig. 12—Semi-Anchor Tower, 66-Kv. Dunstan-Bedlington Line Northeast Coast Power Co., Newcastle-on-Tyne, England

Fig. 13—Straight Line Railway Crossing 66-Kv. Dunstan, Bedlington Line, Northeast Coast Power Co., Newcastle-on-Tyne, England

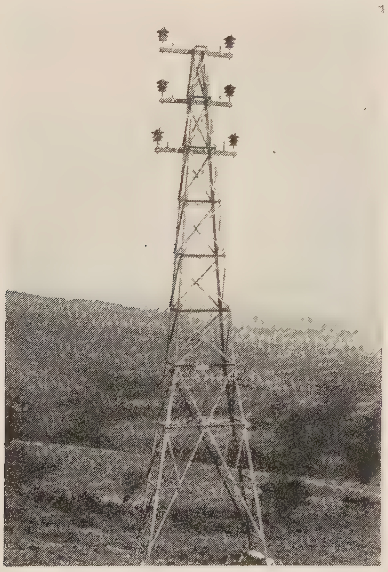


Fig. 14—Type of Standard Steel Tower on 33-Kv. Glen Valley Line of North Wales Power Company

A type of steel line support which works out somewhat cheaper than the usual type of steel tower is shown in Fig. 16.

This structure consists of steel-tubular members mounted in steel-socket pieces, and held rigidly in place by means of high grade steel guys of large diameter.

High-Tension Caples

Among the European power companies operating

Fig. 15—Dead-End Structure of Double Circuit 66-Kv. Line Showing Junction with 66-Kv. Single Conductor Cables Leading to Transformers. Northeast Coast Power Co., Newcastle-on-Tyne, England

Fig. 16—Straight Line Kay Pole for Two 11-Kv., Three-Phase Circuits

Note telephone cable carried on messenger wire.
Average span 330 ft. (100 m.)

cable transmissions of relatively high voltage are the North East Coast Power Co., Newcastle-on-Tyne, England, 66 kv., Union D'Electricité Paris, France,

60 kv., and Provincial Electricity Works Bloemendaal Holland, 55 kv.

There is also a considerable amount of 33-kv. cable in operation in England.

In Italy a 130-kv. experimental cable of the Pirelli type has been in operation for something over a year with promising results.

One source of trouble which has been responsible for a considerable number of breakdowns in high-

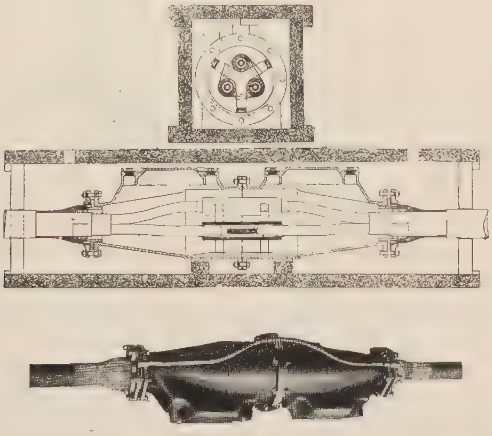


Fig. 17—Three-Conductor, 50-Kv. Cable Joint of British Manufacture

tension cable installations is the result of pressure differences within the sealed cable, where considerable difference in elevation exists throughout a part or whole of its length.

Pressure differences are created if there is any movement of compound used in the cable or its joints and

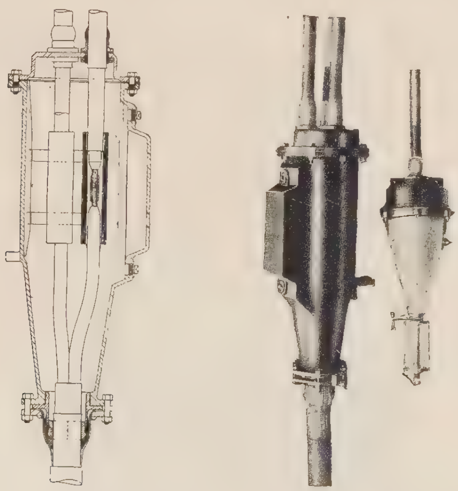


Fig. 18—Three-Conductor, 50-Kv. Trifurcating Box With Single-Conductor Tails and Sealing End, of British Manufacture

any voids caused by such movement of the insulating compound must necessarily weaken the insulation, resulting in failure.

This has led to the development of a type of joint design for filling under pressure, which is expected to ensure complete filling and to prevent voids, but the writer is not able to say whether or not this method has been successful.

Investigations are in progress to determine the feasibility of constructing supertension cables in which a uniform potential gradient would be maintained by means of metallic sheathes, placed between layers of insulation and connected to taps in the transformer winding.[2]

Cables so constructed would be expected to run high in cost, and the splicing and sealing of the ends would seem to present unusual difficulties. However, it is not improbable that continued investigation may develop a cable with solid insulation for supertension voltages at a cost no greater than that of a steel tower line, particularly if there is a saving in cost of right of way, as might be expected in congested districts.

A three-conductor, 50-kv. cable joint of British manufacture is shown in Fig. 17 and in Fig. 18 and a

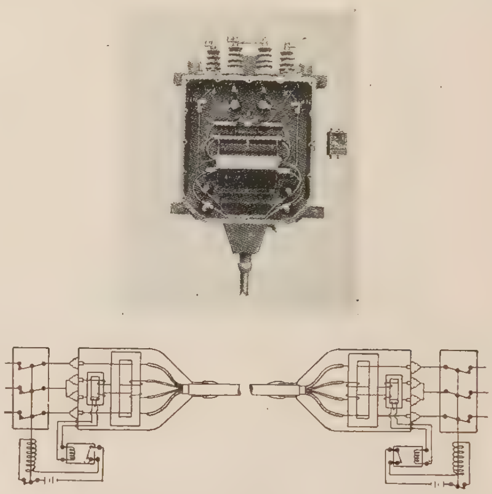


Fig. 19—Connection Diagram of Calender Hunter Four-Conductor System of Current Balanced Cable Protection and Interior View of a Sealing end Showing Physical Arrangement of Balancing Transformer

50-kv. trifurcating box with its single-conductor tails and sealing end.

Practically all distribution in England is accomplished by means of underground cables.

The principal distribution problem is to be found in the London area which is served by about 80 power plants.

A frequency of 50 cycles predominates, but there is considerable diversity as regards phase and voltage.

Low-tension distribution is direct current, two- and three-wire, and alternating current with various systems of connections. Lighting voltages vary from 100 to 240 volts, while power service voltages extend to something over 500 volts. Bulk supply is sold at high-tension voltage.

The main feeder cables of power systems are fre-

2. See paper by A. M. Taylor in *Journ. I. E. E.*, London, England, No. 315, February, 1923.

quently protected by means of current balance, this being accomplished in various ways. In the case of two parallel feeders, the current in one is balanced against the current in the other by means of differential relays which open the circuit-breakers upon a very slight difference in current value.

Cables are in use with six conductors, three of which in a three-phase system are similarly balanced against the remaining three.

A new form of cable specially designed for balanced protection, and which costs somewhat less than six-core cable, has recently been brought out. This system utilizes a special form of four-conductor cable in which two conductors have one-half of the cross-section of the remaining two, and current transformers of special design contained in the sealing ends at each end of the cable. These transformers function to cause a current to flow in a separate winding when the current in the different phases becomes unbalanced. The resultant current is employed to operate a relay arranged to open the circuit breakers.

Fig. 20—Shilbrugg Substation of the Swiss Federal Railways, Showing 66-Kv., Single-Phase Construction

Fig. 21—12,000-Kv-a. Outdoor Transformer Installation of the Northeast Coast Power Co. at Dunstan, England

A diagram showing the connections of the special balancing transformers and relay and the interior of one of the sealing ends is shown in Fig. 19.

High-Tension Equipment

Until quite recently European engineers have conformed to a universal practise of placing high-tension equipment indoors, but with the use of larger units and higher voltages, the outdoor substation is beginnnig to make its appearance.

The recently constructed substations of the Swiss Federal Railways are outdoor type and are relatively simple because of the use of the single-phase system of power transmission and distribution to track circuits.

A photograph of the Shilbrugg substation of the Swiss Federal Railways near Zurich is shown in Fig. 20.

Fig. 21 shows a recent outdoor transformer installation in England with its 66-kv., single-core cable connection. The sealing end for the 66-kv. cable may be seen in the foreground, bolted directly to the transformer tank.

The more prominent electrical manufacturers in England and on the Continent have developed complete lines of equipment for voltages up to 130 kv., while some are prepared to offer equipment for higher voltages.

Lightning protection seems to have received considerable attention on the Continent. The predominating type of arrester has horn gaps in series with water co.umns contained in vertical porcelain receptacles, which are mounted on high-tension insulators. In some cases arresters of the electrolytic and oxide film types of American manufacture are used.

Fig. 22—12,500-Kv-a., 110-12-Kv., Single-Phase, Water-Cooled Transformer Units of British Manufacture

Lightning protection seems to have caused very little concern in England. A length of cable at the end of a high-voltage line is considered by many British engineers to be an excellent method of lightning protection.

On the Continent there seems to have been some fear regarding the solid grounding of high-tension neutrals, although the advantages of grounding are recognized. In some instances a compromise is resorted to, by placing a horn gap in series with the neutral-ground connection. The horn gap is set sufficiently close to break down if a ground occurs.

It is almost universal practise on the Continent to design transformers for forced oil cooling, as this type of transformer costs somewhat less than the water-cooled type. Water-cooled transformers are, however, built in considerable quantities, both on the

Continent and in England, as they are sometimes to be preferred.

Fig. 22 shows part of a group of 12—110-kv., 12,500-kv-a. single-phase water-cooled transformers recently built in England for shipment to India.

There have been developed in England very complete designs of fully enclosed, or co-called "Armour clad" switchgear, for voltages as high as 33 kv.

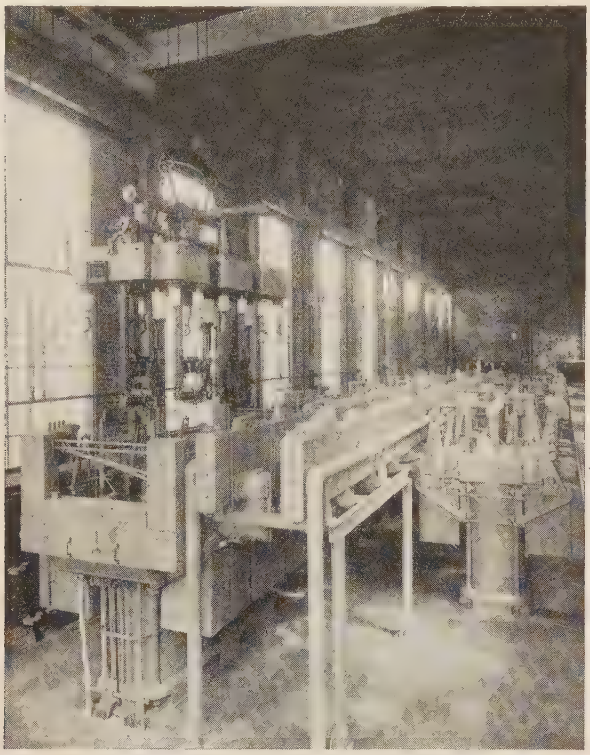


Fig. 23—Portion of 33-Kv., Iron-Clad Switchgear Installed at Barking Station of the County of London Electricity Supply Co.

(On back of Photo)

Showing one-quarter of the ultimate switchgear. In the foreground is seen the sealing off of the end of the busbars and the tail end of the vent pipe leading down through the floor to the outside of the building, but in this case the drawout portion of the main oil circuit breaker is shown removed and suspended above its panel. The operation is interlocked with the crane to ensure that all conductors are dead before it commences.

Fig. 24—Hand-Operated, Armor-Clad, Flame-Proof, Draw-Out Type Feeder Pillar for Industrial and Mining Service

Circuit breaker tank opened for inspection

Fig. 25—Electrically-Operated, Armour-Clad Switch-Gear of Draw-Out Type for Power Station Service, 500,000 Arc Kv-a. Rupturing Capacity

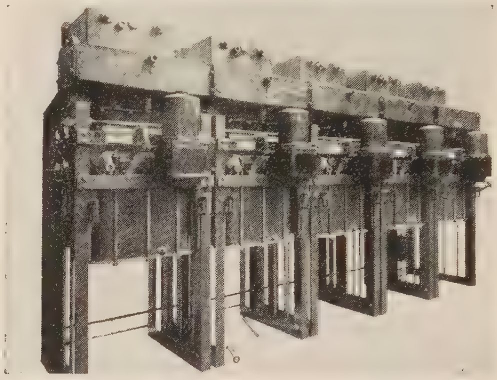


Fig. 26—Electrically-Operated, Armour-Clad Switch-gear of the Drop Tank Type of 250,000 Arc Kv-a. Rupturing Capacity Installed at Talbot Road Power Station, Nottingham, England

When circuit breaker is open tank may be lowered for inspection by means of the crank shown in the foreground. During the lowering process all leads are disconnected and live parts protected automatically.

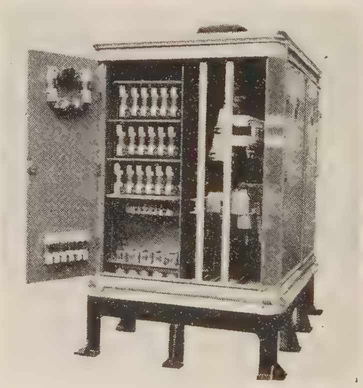


Fig. 27—Self-Contained, Armour-Clad Distribution Substation of British Manufacture

The recent switchgear installation at the Barking Station of the County of London Electricity Supply Co. introduces one of the most modern developments of this type of gear, which is designed for an operating voltage of 33 kv. and rupturing capacity of 1,500,000 arc-kv-a.

Fig. 23 shows one quarter of this gear in place, with one of the circuit breakers withdrawn. In the foreground may be seen the sealing ends of the compound-filled busbar components and the gas-vent pipes leading through the floor to the outside of the building.

One of the features of the Barking Station gear is the very complete system of interlocks, which has been developed to such a point that it is practically impossible to perform any switching operation in the wrong sequence. To make the system fully complete each section is interlocked with the crane so that no circuit-breaker mechanism can be removed from its position until all connections have been made dead.

This type of gear has been extensively developed to cover all classes of power, mining and industrial requirements.

Three examples of anchor-clad switchgear are shown in Figs. 24, 25 and 26.

A complete armour-clad substation containing high-tension switches, distribution transformer and low-tension fuses is shown in Fig. 27.

Conclusion

The writer wishes to express his appreciation to all who furnished or assisted in securing information or illustrations contained in this paper.

Automatic and Supervisory Control of Hydroelectric Generating Stations

BY FRANK V. SMITH[1]

Associate, A. I. E. E.

Synopsis.—*The paper describes the application of automatic equipment and supervisory control to a number of interesting hydroelectric installations.*

A brief description is first given of the operation of standard equipment, the function performed by it and the protective measures provided. Then several typical stations involving single units, multiple units, self-synchronizing and automatic synchronizing are described, together with some test results of the current surges occurring during the starting operations. The paper closes with some comments on the high-speed, synchronous relay type of supervisory control and remote metering.

* * * * *

General

THE installation of hydroelectric stations equipped with automatic or supervisory control has become so widespread that it may not be out of place, at this time, to review some of the more interesting applications in order to show the variety of problems confronting the switchboard engineer and the methods of handling them. A brief description will be given of the scheme of control that has become more or less standardized for this type of station and then an analysis of several installations.

In general, the equipment is either entirely automatic or operated by means of supervisory control from a remote point, the latter scheme becoming more and more popular because of its greater flexibility.

The simplest kind of supervisory control, known as the Audible Type, is used because of the limited number of operations that have to be performed and the call of economy. Only two wires are necessary for this type. A standard telephone, together with a box containing a number of line keys and a dial, similar to that used in automatic telephone equipment, is required at the dispatching point and a relay cabinet at the generator end. Any number of stations up to ten can be controlled with the same pair of wires looping through them. If separate lines are run out radially from the dispatcher, a key is required for each line to connect it to the supervisory equipment.

Every number dialed sends a train of impulses over the line which, by means of rotary selector switches, perform a certain operation in the distant station and an answer back is received through the telephone (or loud speaker) in the form of a number of busses of different tones, the indication being repeated until another number is dialed or the line disconnected. Fig. 1 shows the complete equipment with the exception of the telephone. At the right is the dispatcher's box with dial and on the left the relay cabinet installed in the remote station. The microphone with low- and high-tone buzzers can be clearly seen while at the extreme left are the rotary switches. A battery of 16 volts is required at the generating station while 110 volts is generally used at the dispatcher's end.

The first operation is to connect the correct station to the supervisory control. This is done by throwing the line key and dialing the number of the station desired—perhaps No. 3. A selector switch then operates in each station stepping to Point 3. This is so arranged that when it stops on any point other than the number of its own station, it sets up a lock-out which prevents further action; but at No. 3 it operates another rotary switch that completes a circuit to a buzzer three times every revolution giving three buzzes in the telephone

1. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

which are repeated until the circuit is interrupted from the dispatching station by further dialing.

The next operation may be to determine the head of water in the forebay. The maximum variation in head is divided into 10 parts with a float switch making contact as it moves over the range and these points are connected to a similar rotary switch so that on checking water head a number of buzzes are heard indicating the point on the scale at which the float stands.

The dialing of another number will set the master

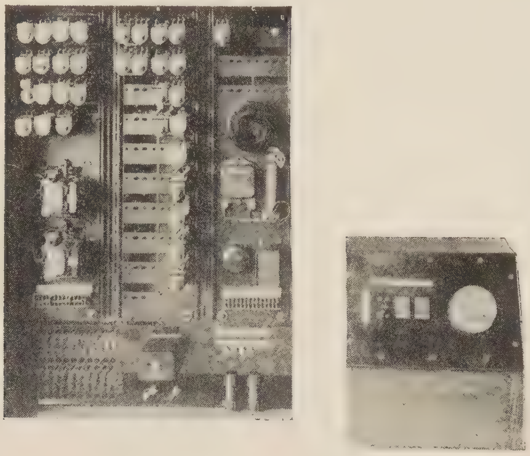


Fig. 1—Audible Type Supervisory Control

relay in the station in operation and the unit will start up and put itself on the line. In stations which are entirely automatic, this master element is energized by such a device as a time clock, frequency relay, float switch or something of the kind which starts the machine when certain predetermined conditions exist.

In general the automatic equipment is arranged to perform the following functions:

a. Start the unit, provided normal conditions exist, upon the operation of the master-starting element

b. Stop the unit by means of the master element

c. Protect against generator overvoltage

d. Protect against motoring of the generator

e. Prevent the opening of the line circuit breaker on short time periods of low a-c. voltage

f. Protect against discharge of the battery. Battery control with automatic means for charging is the most reliable method available because of its complete independence from the a-c. system with its occasional voltage dips.

g. Shut-down the unit temporarily if:

1. The line is short-circuited or overloaded to a point that the machine voltage drops below 80 per cent of normal for several seconds
2. The machine windings tend to overheat
3. The unit overspeeds
4. The unit is caused to operate on a reverse, single or badly unbalanced phase line.

h. Shut-down and lock-out the unit if:

1. A bearing overheats
2. The generator field fails
3. The oil pressure in the governor falls below a safe value
4. The differential relays operate

i. On normal shut-down, the oil circuit breaker and field contactor are prevented from opening until the gates reach the no-load running position. This gradually transfers load to other units on the system and prevents sudden dropping of load on the automatic generator.

j. Prevent the generator from starting if:

1. The unit has been locked out by any function under *h*
2. Conditions as listed under *g* have not been righted

The unit may be provided with a periodic relay so arranged that in event of its being shut-down temporarily as under *g* it will attempt to start only a predetermined number of times and then lock itself out.

The items listed under *h* represent serious troubles in the machine and operate an annunciator lock-out relay which has a series of targets, one for each device, and tells at a glance the cause of the shut-down.

Where supervisory control is used, a warning signal is sounded in the dispatching station whereupon the cause of the trouble can be checked and the station started again if it is of a minor nature.

Single Unit Stations

One of the most interesting cases of the application of this type of control is to be found on a property of the Interstate Public Service Company in the Middle West. Here there is an old barge canal on which are located five hydroelectric stations each containing one vertical

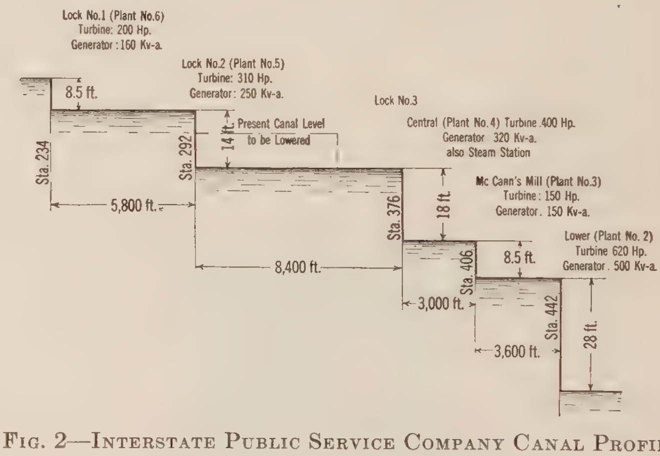


Fig. 2—Interstate Public Service Company Canal Profile

generator. These are known as plants No. 2, 3, 4, 5 and 6 stretched over a canal length of about four miles with machines rated at 500, 150, 312, 250 and 150 kv-a. respectively. Plant No. 4 is the Central Plant and is used as the dispatching point, as a steam station is also located close to the canal and operators are therefore nearby. All machines generate at 2400 volts and are tied together and to the rest of the system with a transmission line at this voltage. Each machine has a direct-connected exciter of ample capacity. Fig. 2 shows the lay-out of the canal.

The four automatic stations are controlled from Plant No. 4, out of which one pair of lines runs to Plants No. 5 and No. 6 and another pair to No. 2 and No. 3. Plant No. 4, itself, is manually operated.

When starting up a station, the key to connect the East or West line to the supervisory is thrown at the control desk and the number of the desired station is dialed. On receiving assurance that the correct plant is connected to the line a check is made of the water-level. If this is suitable the station is started by dialing the proper number. A solenoid on the governor is then energized and the gates begin to open till a point is reached to give approximately normal speed at no load. As the wheel comes up, the exciter, which is not yet connected to the a-c. generator field but has most of its own rheostat short-circuited, builds up its voltage and closes the main line breaker at approximately synchronous speed. As the generator is provided with damper windings it pulls rapidly into step, assisted by the field excitation which is thrown on by an auxiliary switch on the main breaker. The generator then operates in the usual manner under the control of a standard vibrating regulator. This self-synchronizing method of putting a machine on the line is the simplest scheme that is available and even eliminates the necessity of a speed switch to determine the point at which the breaker is closed—this point being set by exciter voltage. As the system is very large compared with the size of the units, no appreciable shock is felt on the line when the machine is closed.

In order to utilize all the water available, the three smaller units at Dams Nos. 3, 5, and 6 operate under float type of load control; the gate opening depending entirely on the head of water available. On the larger units the usual type of speed governor is used with the addition of a float attachment for limiting the load on low head.

The supervisory control performs the usual functions of starting and stopping the units and reading the head of water, power output (determined from the gate opening) and breaker position. In addition, a point is furnished for voltage control; this is provided by means of a contactor which short-circuits a section of the voltage regulating rheostat on the generator and, in effect, recalibrates it for a different voltage. Two trouble horns are furnished in the dispatching station, one for the east and one for the west line. When any machine locks out due to operation of its protective equipment, the horn sounds until the station in trouble is located by means of the supervisory system.

On another part of this system there are now being installed two generators rated at 300 kv-a. and 400 kv-a., 2300 volts in different stations a few miles apart. These are to be entirely automatic, starting and stopping by means of a combination of float switch and time-clock so arranged that the machines will operate according to a predetermined time schedule providing the water-level is within the proper limits.

Multiple-Unit Stations

In these cases there has been but one generator per station. However, installations of two or three machines in the same plant are quite common and give rise to no particular problem. When supervisory control is used, the separate units are handled almost independently as if they were in different stations; the load and breaker positions, etc., of each unit are read separately, although, of course, one water-level indicator is sufficient for the station. When under complete automatic control one machine is given preference so that it will always start first and the others will follow in order as conditions demand. A simple knife switch is generally supplied so that the No. 1 machine can be changed at stated intervals and thus distribute the service over the various units. Sometimes, in order to

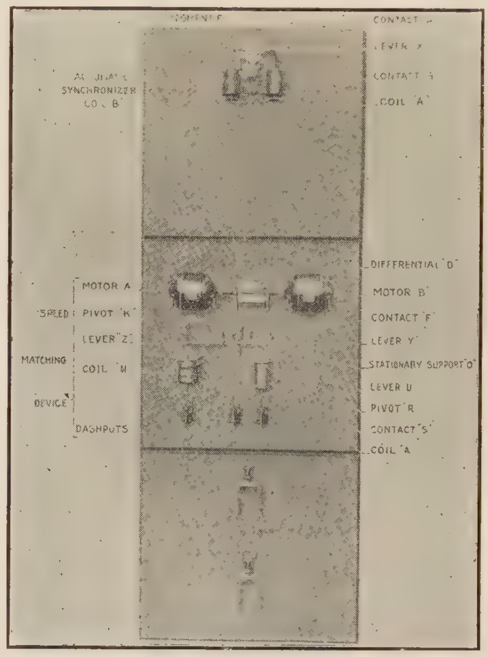


Fig. 3—Automatic Synchronizer

obtain the maximum output from the station, arrangements are made so that as many machines as possible will operate at their maximum points of efficiency rather than distribute the load equally over all units.

One of the most interesting applications in the country is to be found on the property of the Wisconsin Public Service Company on the Peshitgo River. Here, there is a string of four plants at Caldron Falls, High Falls, Johnson Falls and Sandstone Rapids, connected by a 66,000-volt line which runs south to Green Bay. High Falls is a manually operated station of 8750-kv-a. from which the other three are controlled.

Automatic Synchronizing and Self-Synchronizing

The first automatic to be installed was Johnson Falls which contains two 2200-kv-a., 2400-volt, 150-rev. per min. vertical machines with direct-connected exciters and is located three and one-half miles down

the river from High Falls. Since High Falls would be the only station in operation when the machines at Johnson Falls were started up it was felt that if the usual self-synchronizing scheme of throwing the generator on the line without field at approximately synchronous speed were utilized, the bump on the system might be objectionable, and it was decided to make use of the automatic synchronizer. In any case in which the incoming generator capacity is an appreciable percentage of the system kv-a. the use of the automatic synchronizer is essential if smooth operation is to be secured, in fact, in some cases where the machine is on the end of a long line with limited capacity an attempt to throw it on without synchronizing might well produce such a drop in voltage as to allow any synchronous motors on the system to drop out of step.

The automatic synchronizer shown in Fig. 3 is composed of two parts—the speed matcher and the synchronizer proper. The generator is brought up to speed with its field excited from the direct-connected exciter under the control of its voltage regulator and as it nears synchronism the speed matcher comes into play. This consists of a pair of small single-phase motors working through a differential to a contact-making device. One motor is connected to the leads of the incoming machine and the other to the bus. Depending on whether the machine is below or above synchronism, contact is made through the differential to raise or lower the speed of the water-wheel through

Fig. 4—Control Panel for Rheostatic Regulator

the electrically operated governor so that it is held at synchronous speed. An anti-hunting device prevents oscillations. The automatic synchronizer then functions to close the breaker when exactly in phase. This consists of two solenoids working through a lever mechanism and an oscillating segmental contact. It can be seen mounted on the top of the panel. One solenoid is arranged with coils excited from a potential transformer connected in such a way as to have a maximum pull when the voltage of the machine is in phase with the bus and zero pull when directly out of phase. The other solenoid is connected in the reverse manner so that as the machine approaches synchro-

Fig. 5—High Speed Face Plate for Rheostatic Regulator

nism, the pull of the two solenoids reaches a maximum alternately and oscillation takes place in the lever mechanism. The frequency of these oscillations falls as the machine approaches synchronism and when it reaches that corresponding to a complete revolution of a synchroscope needle in approximately five seconds the oscillating segment makes contact long enough to complete a circuit to the control relay and close the machine breaker connecting it to the line. The machine then continues to operate when under the control of its voltage regulator. Synchronizing by this means is much more rapid and more accurate than could be done by hand.

An interesting point in connection with the installation is the use on the generator of the high speed face-plate rheostatic voltage regulator rather than the vibrating type. This regulator is coming into very common use in hydro stations—particularly automatic stations—because of its extreme simplicity and very satisfactory operation. The exciter voltage is maintained constant and regulation takes place entirely on the main field rheostat. A typical control panel is shown in Fig. 4 and the motor-operated face plate in Fig. 5. The forward and reversing contactors of the motor are shown on the top of the panel while the control element proper is below. Variation in bus voltage, working through the lower mechanism, results in rapid cutting in or out of resistance with suitable anti-hunting devices to prevent over-travel of the motor. In this regulator the time element of the exciter field is eliminated so that its speed of operation is quite comparable with the vibrating type and is particularly applicable where heavy field currents necessitate a large number of relays on the vibrating regulator.

The second station to be installed on this system was

Caldron Falls about seven mi. up the river from High Falls where there are two 4000-kv-a., 2300-volt vertical machines. It was decided in this case to use the more usual scheme of self-synchronizing to put the machines on the line. For this reason they were provided with damper windings (these being unnecessary, of course, in the case of Johnson Falls) and a speed switch which operates to close the machine breaker at 95 per cent speed connecting it to the line without field, the field being applied by means of an auxiliary switch on the breaker. Another departure from the practise at Johnson Falls was the use of a vibrating regulator for each machine rather than a rheostatic regulator.

A very interesting picture of the characteristics of the two schemes of starting can be obtained from oscillographs taken at the time of closing the generator breaker. Fig. 6 shows the self-synchronizing generator.

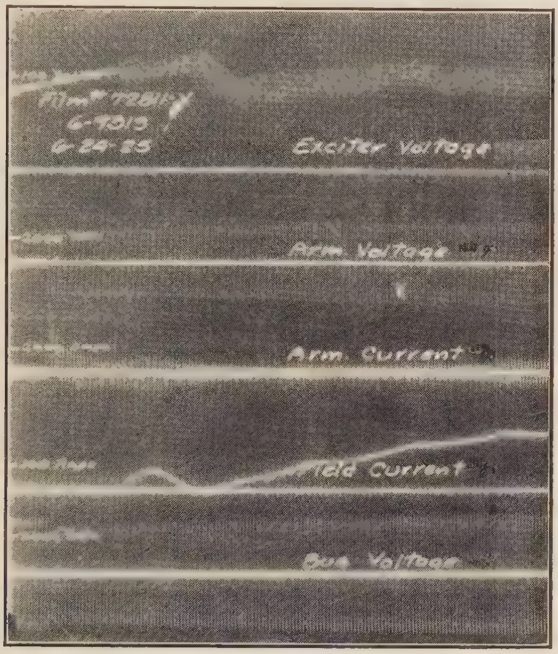


Fig. 6—Oscillograph of Self-Synchronizing Generator

It will be seen that as there is only the reactance of the winding to limit the current, it rises to seven and one-half times full-load current. Several seconds elapse before it has dropped to full load. When the breaker closes, the voltage falls to 75 per cent of normal for a few cycles. Fig. 7 shows the action with an automatic synchronizer. The armature current reaches only 35 per cent of full load and oscillates for a few seconds.

In deciding on the type of control to be used in the latest plant at Sandstone Rapids, experience obtained from the other two pointed to the use of an automatic synchronizer and the face plate rheostatic regulator. Here there are two 2400-kv-a., 6600-volt, 150-rev. per min. machines with direct-connected exciters. In general, the equipment will be very similar to Johnson Falls.

An interesting point in connection with these stations is that they are arranged for starting, not only from the supervisory control, but also from a low-frequency relay. This relay will energize the master element if the frequency drops to 57 cycles; a delay of a few seconds being provided to take care of momentary dips. Only one relay per station is necessary and after it starts machine No. 1, it is transferred to No. 2 to be ready to start it when required. The machines close down when a predetermined underload exists for a stated time, variable up to 30 min.; shutting-down takes place in the reverse order from starting up.

In order to show the extreme flexibility of this type of supervisory control it might be well to enumerate the number of different operations that can be performed by its means in the Sandstone Rapids Plant.

1. Start machine No. 1
2. Stop machine No. 1
3. Release lock out on machine No. 1. This is to allow the machine to operate as a complete automatic station starting by means of its frequency relay if conditions demand.
4. Supervise water-level machine No. 1
5. Supervise gate-opening machine No. 1
6. Increase load on machine No. 1
7. Decrease load on machine No. 1
8. Raise upper limit of gate-opening machine No. 1
9. Lower upper limit of gate-opening machine No. 1
10. Close breaker No. 1. This is a high-tension oil circuit breaker connecting to one of the 66,000-volt feeders.
11. Open breaker No. 1
12. Supervise breaker No. 1
13. Start machine No. 2
14. Stop machine No. 2
15. Release lock out on machine No. 2
16. Supervise water-level machine No. 2
17. Supervise gate opening machine No. 2
18. Increase load on machine No. 2
19. Decrease load on machine No. 2
20. Raise upper limit of gate-opening machine No. 2
21. Lower upper limit of gate-opening machine No. 2
22. Close breaker No. 2
23. Open breaker No. 2
24. Supervise breaker No. 2

Application to Old Stations

Automatic operation shows such economy that it is not only applied to new stations, but also many old ones are being changed over by the addition of the necessary equipment. In one station just put in operation under supervisory control, there is one 1000-kw., 100-rev. per min., 2300-volts, waterwheel generator and one 500-kw., 120-rev. per min., 2300-volt generator both excited from a 50-kw., 125-volt, 500-rev. per min. waterwheel-driven exciter. In general a direct-connected exciter is by far the more desirable for automatic control but, of course, in an old station it cannot always be provided.

Since the machines had no damper windings, they could not be expected to pull into step by the usual self synchronizing method and an automatic synchronizer was, therefore, provided. The station is operated by

supervisory control from a point two miles away. No voltage regulator is used as the machines operate with fixed excitation. The first operation is to start up the exciter and when it is up to voltage machine No. 1 or No. 2 is brought up to speed and field applied. As it nears synchronism, the automatic synchronizer is connected in circuit and the machine synchronized to the line. Only one synchronizer is provided for the two machines and it is automatically connected to the incoming machine as it speeds up.

In addition to the control and supervision of the

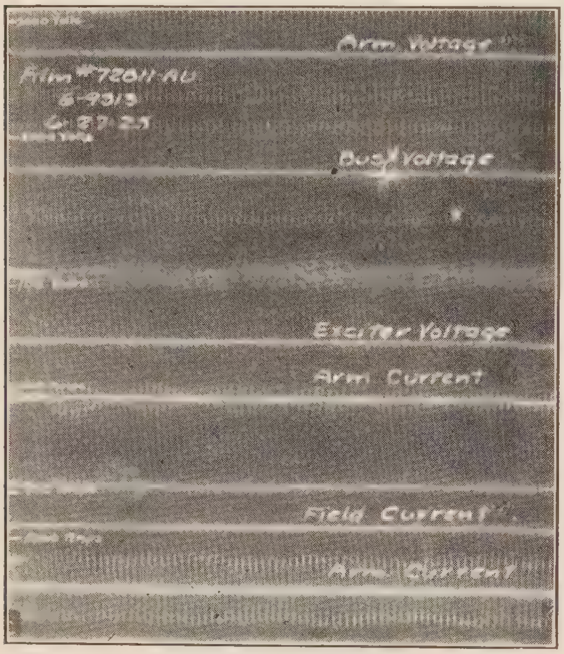


Fig. 7—Oscillograph of Generator Automatic Synchronizing

generators proper, there are 9-feeder circuit breakers in the station which are operated over the supervisory equipment.

Large Automatic Unit

One of the largest automatic generators to be put in service will be that of the New England Power Company rated at 9000-kv-a., 2300-volts, three-phase, 60-cycle, 180-rev. per min. with direct connected exciter. The equipment is entirely automatic and in general follows along the usual lines. The machine is started by a combination of time clock and the energizing of the high-tension line from the neighboring station of Davis Bridge, three mi. away. The generator will come into service when the high line is energized providing the time clock has completed contact. The latter can also be arranged to take the generator off and put it on again over the noon hour.

The machine is provided with damper windings and comes on the line by the self-synchronizing method. Remote control is provided from Davis Bridge for adjusting the load on the governor motor when desired but there is nothing further in the way of supervision. As the automatic unit will be on the stub end of a line, the output can be measured at Davis Bridge by the incoming meters.

The voltage is stepped up from 2300- to 110,000-volts through three 2000-kv-a. transformers to tie in with the power system. An emergency motor generator set is provided for excitation in case of trouble with the direct-connected exciter.

Synchronous Visual Type Supervisory Control

In all these installations, the same kind of supervisory control has been used—the audible type—because it is quite sufficient to take care of all requirements. It is possible, however, that what is known as the Synchronous Relay Type of control will find application where remote synchronizing is desirable or where there are such a large number of stations to be controlled that a constant visual indication is required of the status of the equipment in each one.

This apparatus is extremely flexible in its application and there is practically no limit to the number or kinds of operations that can be performed. It does not operate on the impulse or code principle but really sets up a complete circuit from the dispatchers board key over two line wires to the control relay of the apparatus to be operated. This can be a circuit breaker or any indicating device such as a float switch, ammeter or voltmeter which can be arranged to reproduce its indication at the dispatching point.

The apparatus consists of batteries of relays at

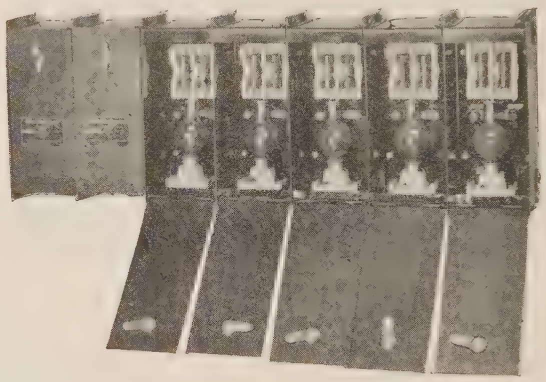


Fig. 8—Supervisory Control Protective Tubes

both ends of the line; these operate in synchronism and are kept together over a two-wire drive circuit with interlocks so arranged that the relays must operate in a predetermined order and corresponding relays at both ends of the line must operate together otherwise the whole equipment comes to rest and refuses to function. Each pair of relays corresponds to some particular operation in the automatic station and as they operate they step another two wire signal line from point to point so that at any particular instant a complete circuit is provided over these signal wires from the control key in the dispatcher's office to the proper apparatus in the automatic station.

When it is desired to perform any particular opera-

tion, the corresponding key is depressed and then the drive circuit set in operation. The relays operate in synchronism until the signal circuit reaches the key that has been operated and thus a complete circuit has been completed through to the apparatus and the operation takes place. In the case of remote synchronizing, voltage transformers are connected to points in the substation cabinet and a synchroscope to corresponding points at the dispatcher's end. The circuit breaker to be closed is arranged to be the next point in sequence so that, the moment synchronism is reached, the dispatcher operates a key which instantly transfers the signal line from the synchroscope point to the breaker point and closes the breaker.

Continuous lamp indication is given of the position of all equipment and telltale lights are provided to show any automatic operation.

Supervisory Protective Equipment

It might be well to mention here the necessity for some kind of apparatus to protect the supervisory control equipment from line disturbances. It is very common to find the telephone wires used for the supervisory run underneath the high-tension transmission lines where they will be subject to induced voltages from the high-tension line as well as the possibility of direct contact. In order to prevent such over-voltages getting into the control equipment vacuum tubes to provide a path to ground are connected to the supervisory line at both ends. Fig. 8 shows a battery of such tubes. Each tube contains four electrodes. In the case of a two-wire line, an electrode is connected to each line and the other two are connected together and to ground. The four are spaced so that they will discharge at a difference of potential of about 250 volts between pairs, thus preventing any higher voltage than this remaining on the control wires. Small fuses are furnished for connection between the tubes and the supervisory and in the case of overhead wires paralleling high-tension lines, fuses of the transmission line voltage rating are also used on the line side. These vacuum tube protectors have been known to take care of the most severe conditions without difficulty.

D-C. Hydro Station. Although the great majority of installations are for a-c. generators there are some cases where vertical d-c. machines have been used. These are provided with the necessary $W R^2$ and overspeed capacity and use Kingsbury thrust bearings. The commutator is placed below the rotor to prevent carbon and copper falling in the windings.

The machines are entirely automatic in operation, being controlled by a float switch. As the water-level rises the float makes contact and starts the governor oil pump motor and when the proper operating pressure has been reached, an electric solenoid puts the governor in operation, the gates open and the machine comes up to speed. The automatic voltage regulator then comes into operation and balances the voltage of the machine with the bus by working on a motor-operated field rheostat. The main d-c. breakers are closed and the load taken by the generator is regulated by the water-level; the float switch operates over a rheostat which is inserted in the voltage regulator circuit thus recalibrating it and allowing it to regulate for higher or lower voltage and therefore larger or smaller output. The units are shut down at a predetermined minimum head.

In addition to balancing the voltage at start and regulating it for load the regulator has a third element which limits the output of the generator in case of trouble. In event of overload, the voltage is cut down thus limiting the output and if the overload continues the thermal relays lock the machine out.

Conclusion

While no attempt has been made to go into the equipment supplied for any of these plants in very great detail, it is hoped that sufficient has been described to show the variety of applications confronting the automatic engineer, the types of problems that are encountered, and the extreme flexibility of the equipment in its capacity to take care of practically any conditions that can arise.

ELECTRICAL HOUSEHOLD APPLIANCES IN THE NETHERLANDS

A large demand for modern electrical household appliances has recently been created in the Netherlands as a result of the activities of the municipal electric works at Amsterdam where American products are generally favored.

The general application of electrical appliances has been restricted by the comparatively high rates, consequently the number of electric household appliances used has been small. Special rates are now being quoted for electricity used during the daytime, and the municipal electric works at Amsterdam has announced that it will supply electric energy at a lower "night tariff" from 11 p. m. to 7.30 a. m.

The municipal enterprise is demonstrating devices in a special showroom. Among the articles shown is an electric stove which stores heat during the night hours for use the next day. When the stove, which weighs about 330 lbs. is fully charged, the inside temperature is 275 deg. cent., while the outside is 70 deg. cent.

Various types of electrically operated refrigerators are also on exhibition. Water tanks with a capacity of 1½, 6, 10, 40, and 60 gallons are available. The water is heated to 85 deg. cent. Radiation is at the rate of three-quarters of a degree per hour, so that hot water will be available all day.

The municipal works are supplying purified, dry air in cylinders which can be placed in bedrooms of people suffering from asthma.

Abridgment of

Synchronous Machines

I—An Extension of Blondel's Two-Reaction Theory

BY R. E. DOHERTY[1] and C. A. NICKLE[1]

Associate, A. I. E. E. Associate, A. I. E. E.

Synopsis.*—Blondel treated salient pole machines by resolving the fundamental space component of m. m. f. along the two axes of symmetry—the direct axis of the pole, and the quadrature axis between poles. Using this idea and applying harmonic analysis, Blondel's theory has been extended in the present paper to a comprehensive system of treatment in which the effect of harmonic m. m. fs., as well as the fundamental and also of field m. m. f. in the quadrature axis, as well as in the direct have been taken into account.*

It is shown that the "armature leakage flux" which causes reactance voltage drop in synchronous operation comprises all fluxes due to armature currents which generate fundamental voltage except the space fundamental component, the latter constituting the total flux of "armature reaction."

Impressing upon the variable air-gap permeance those space harmonics of m. m. f. which are due to the fundamental time component of current and which therefore rotate at various fractional speeds produces odd space harmonics of flux rotating at many different speeds and in opposite directions. Some of these listed in Table I produce fundamental voltage, but most of them generate time harmonics. The former, which are reactive voltages, are only those of the nth space order rotating at one nth speed—that is, those which correspond in space order and speed to the harmonic m. m. fs. The corresponding reactances are definitely defined in Appendix C in terms of permeance coefficients, and means are outlined for quantitative determination of such coefficients from graphically constructed field plots. Although, strictly, there are as many field plots required as there are significant m. m. f. harmonics, an approximation, developed in Appendix B, is given in which only one plot is necessary, other permeance waves being derived therefrom.

It is shown that only the average term and the second space harmonic of the permeance series affect the fundamental voltage. Hence, unless it is required to calculate the harmonic voltages, only those two terms of the permeance series need to be determined.

In the application of the results, the fundamental voltages thus produced by the armature currents are superposed upon that due to current in the field winding, which latter has been previously treated. This gives the vector diagram, Fig. 19, from which the steady state relations are set down in equations.

In Part II, the steady-state angle-power relations are developed, including an interpretation of the "reluctance term" in the power or torque equation.

In Appendix D, the vector diagram for salient pole machines is interpreted in terms of the well-known Potier diagram for cylindrical rotor machines. Also the effect of saturation both on angle-power relation and on the value of excitation required under load is discussed.

Subsequent papers in the near future will present results which have been obtained from the application of the method and point of view here outlined to the solution of problems relating to abnormal operating conditions of synchronous machines.

* * * * *

INTRODUCTORY

THE ever widening application of synchronous machines and their great importance as a factor in the operation of power systems have created the occasion for an extended study of their behavior under the various normal and abnormal conditions. The results of the investigation comprise not only the determination of such operating characteristics, but also extensions in fundamental theory and in mathematical facilities for applying it. It is the authors' purpose to present the results of the investigation in a series of papers, the present one dealing with the theory relating to steady-state, polyphase operation.

The present work is essentially an extension of Blondel's[2] treatment, and an application of the results to definite problems. His fundamental conception of resolving the armature m. m. fs. and fluxes in salient pole machines into two space components—one in line with the pole axis, the other in quadrature thereto—is the basis of the present study. The fundamental premises are extended, and new constants which are necessary to characterize the performance are defined and incorporated in the equations. As in any engineering analysis, this has involved certain assumptions, carefully defined, which would simplify the equations to a practical degree, but which would not throw the calculated results beyond the limit of reasonable accuracy. That is, the predominating factors which practically determine the characteristics have been included, and those have been omitted which complicate the equations without significantly affecting the calculated result. The final equations are thus relatively simple, considering the nature of the phenomena related.

Lyon[3] has treated the *flux* distribution, voltage and power of a synchronous machine by an interesting application of harmonic analysis to the flux waves which must exist. He starts with a general equation for the complicated resultant flux wave; hence, the resulting series contain coefficients which it would be very difficult to determine. However, it is true, as Prof. Lyons says, that it is "useful to know what harmonics may be present even when their magnitudes can not be calculated." The present paper, while applying the same general method of attack, *i. e.*, harmonic analysis, nevertheless starts with the resolution of *m. m. f.* waves, instead of *flux* waves, and takes advantage of the symmetry embodied in salient pole

1. Both of the General Electric Co., Schenectady, N. Y.
2. Bibliography 11.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

3. Bibliography 7.

machines, by making the resolutions along the two axes of symmetry,—*i. e.*, applies Blondel's idea. This treatment gives m. m. f. waves spread over definite permeance distributions, thus making it possible to determine the coefficients of the significant harmonics of the flux waves.

Thus several aspects of the problem have been treated during the investigation; an extension in fundamental theory, comprising an harmonic analysis of the phenomena in the air-gap, and the inclusion of exciting field ampere-turns in the quadrature axis, the definition of characteristic constants, and thus, to this extent, a basis for their determination; the formulation of characteristic equations; the excitation-voltage-load characteristic; angle-power relations under steady and transient states; short-circuit phenomena under steady and transient states, single phase and polyphase; and mechanical forces and torques due to electromagnetic reactions under various conditions.

The present paper is in two parts. The first interprets and extends the theory relating to steady-state conditions, including definitions of the essential constants; constructs the excitation-voltage-load diagram, and shows the relation of this to the corresponding familiar diagram for cylindrical rotor construction. Part II treats the steady-state power-angle relations.

I. General Theory

Percentage Representation of Quantities. It is convenient to express the quantities involved in percentage (as a fraction) of their normal values. While the base of the fraction for each quantity has definite dimensions, the fraction is, of course, a numeric, and its use avoids cumbersome conversion factors in the equations. Nevertheless, the results thus expressed by fewer symbols are none the less definite. It is believed that many mathematical treatments of engineering problems could be immensely simplified in this way.

On this basis:

Unit voltage is normal rated voltage.

Unit armature current is normal rated current.

Unit power is normal three-phase power.

Unit impedance is that impedance through which normal voltage at normal frequency causes normal current to flow.

Unit field current is that field current which induces normal fundamental, open circuit voltage at normal speed.

Unit space fundamental flux is the flux which rotating at normal speed induces unit voltage.

Unit flux density is the maximum density of the unit fundamental flux wave.

Unit space fundamental magnetomotive force is the resultant fundamental magnetomotive force produced by normal three-phase armature current.

Unit permeance coefficient is that coefficient which, multiplied by unit m. m. f., gives unit flux density.

Unit time is the time required for one cycle of fundamental frequency.

Unit angle is 2π.

Unit speed is normal synchronous speed.

All armature voltages and currents are per phase.

Armature Current Phenomena. It has been shown by Arnold and others[4] that in a synchronous machine, the *space* distribution of *m. m. f.* due to each armature coil can, under certain reasonable assumptions[5], be resolved into rotating space harmonics. The superposition of these m. m. f. distributions due to all coils produces an interesting and highly convenient result—namely, a number of space sinusoids of m. m. f. of different pole spans, rotating at different speeds, some forward, some backward. Thus, for instance, in a balanced three-phase system, the fundamental sinusoid alone rotates at synchronous speed with respect to the armature, *i. e.*, with the field poles; the third harmonic, vanishes; the fifth, with a pole span of one-fifth, rotates backward at one-fifth of synchronous speed; the seventh, with a one-seventh span, forward at one-seventh speed; the ninth vanishes; the 11th, backward, and so on. Stated in other words, for balanced current (sine wave in time) in a three-phase armature, there are a number of different, independent, *space* sinusoids of *m. m. f.*, each rotating at a different speed; and they exist as sinusoids, of course, regardless of the salient-pole character of the magnetic circuit of the rotor, so long as the poles are symmetrical. Fig. 1 shows the fundamental and fifth of such a system at one instant of time.

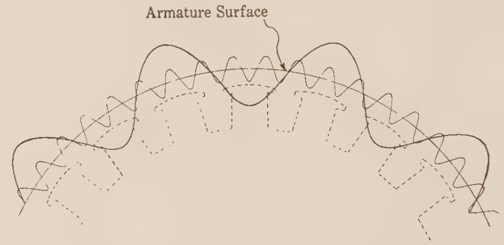


FIG. 1—TRAVELING SPACE SINUSOIDS OF M. M. F.

While the method is here discussed in terms of a three-phase machine, the general theory obviously applies to any polyphase system. In two-phase, the only difference is in the number of harmonics dealt with. For this case, the space harmonics of m. m. f. are as follows; the fundamental, forward at synchronous speed, the 3rd backward at 1/3 speed, 5th forward at 1/5 speed, etc.—all of which may be treated in the foregoing manner. In single-phase, the method of analysis is the same, but the results involve some additional

4. Bibliography 2; and 4, chapter VII.

5. The particular assumptions involved in order that m. m. f. with respect to the rotor may be definite at each point of the armature surface are infinite permeability of the armature iron, no slots, armature current concentrated at points along the armature surface, and symmetrical field structure.

Subject to these assumptions, the armature m. m. f. becomes equivalent to a distribution of magnetic potential along the armature surface.

constants which enter the problems of transient state; hence this case will be treated in a later paper.

If there are time harmonics in the current, each one of them will produce its own system of space sinusoids of m. m. f., which will be like that produced by the fundamental term in all respects except that the speed of rotation of each sinusoid will be increased by the order of the time harmonic of current. For instance, if the current in each phase comprises a fundamental and a fifth harmonic, there will be two systems of space sinusoids: one due to the fundamental, as described in the foregoing paragraph; and another in which the sinusoids of full pole span (*i. e.*, fundamental in space) rotates at five times synchronous speed, the third vanishes, the fifth (one-fifth pole span) at five-fifths speed, and so on.

It is possible to superpose the armature m. m. fs.[6] as in the foregoing, because they are all assumed[7] to be distributed along the armature surface. However, the field pole m. m. f. is not. It is distributed radially and at some distance from the armature currents. Hence, the superposition of the armature and field m. m. fs. is not permissible. But all of the *fluxes* at any point on the armature surface, produced by all of these m. m. fs., can be superposed; likewise, the corresponding voltages.

So the problem is to determine all of the space harmonics of flux which are produced by all currents of both the field and armature, and which generate voltage in the armature conductors; then to superpose such of them as are significant, in order to determine the resultant voltage. In addition, there are voltages due to those fluxes which do not appear in the air-gap—namely, slot leakage and end-winding leakage. These fluxes are practically proportional to, and in phase with, the armature current, and thus produce corresponding reactive voltages. The resultant of all of the foregoing voltages is, of course, the terminal voltage.

Turn now to the flux waves produced by the rotating sinusoids of m. m. f. Under steady-state operation the fundamental space wave of the armature m. m. f. rotates at synchronous speed with the field poles, at some definite angle of displacement. Hence whatever may be the shape of the flux wave thus produced, it is nevertheless steady in value and fixed with respect to the poles. All of the space harmonics of m. m. f., on the contrary, rotate at speeds different from synchronous speed, and therefore travel over magnetic paths of varying permeance, each wave of m. m. f. producing a pulsating, tufting, rotating flux—rotating, as it were, at a non-uniform velocity with respect to the poles, yet, at the same time, pulsating in magnitude.

6. Neglecting the magnetic reluctance of the armature.

7. The assumption is that the m. m. f. wave of each coil is approximately a square wave, and hence that the total current in each slot is concentrated in a conductor in the center line of the slot, at the surface of the armature, as illustrated for a particular case in Fig. 2.

This is, of course, a complicated phenomenon, but it can be handled analytically as follows:

1. Resolve each rotating space harmonic of m. m. f. into two stationary pulsating waves with respect to the poles.
2. Determine the two corresponding stationary (with respect to the poles), pulsating *flux* waves produced by (1).
3. Combine the flux waves of (2) into *rotating* space harmonics of flux.
4. Determine the component voltages which the space harmonics of flux in (3) generate.

The same method of analysis, of course, applies to the space fundamental of m. m. f. as well as to the space harmonics of m. m. f., the essential difference in result being that the speed of the space harmonics of *flux* due to the space fundamental of m. m. f. is zero with respect to the poles.

Before proceeding to such analysis, it is necessary to resolve the system of three-phase, balanced, sine-wave (in time) currents into two component three-phase systems: one in which the current in each individual phase reaches maximum at the instant the axis of the field pole coincides with the axis of magnetization of the

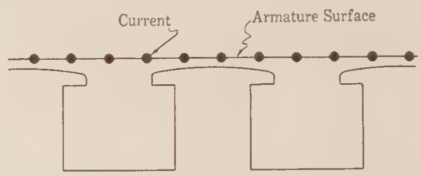


FIG. 2—ASSUMED CURRENT DISTRIBUTION ALONG THE ARMATURE SURFACE

phase under consideration—this is called the *direct* component because it produces the direct component of armature reaction; and another in which the current in each individual phase reaches maximum at the instant its axis of magnetization is in line with the axis midway between poles, that is, one-quarter cycle later—this is the *quadrature* component. Each of these complementary, three-phase systems has its own set of rotating space sinusoids of m. m. f. as described in the foregoing.

While the general case is treated in Appendix A, the physical significance is necessarily somewhat obscured in such a treatment. Hence it appears desirable to illustrate by carrying through the analysis of some particular harmonic,—say the fifth. The procedure is the same for any harmonic, including the fundamental.

The first step is to define the references clearly. Since the resolution of m. m. fs. is to be made with respect to the poles, the space reference will be taken as the axis of a field pole, and time will be reckoned from the instant the axis of magnetization of some particular phase, say phase 1, lines up with the pole axis. Thus, referring to Fig. 3A, the electrical angle α is measured from the axis of pole a in the direction of rotation. The position of the axis of phase 1 with reference to pole a is shown for the instant $t = 0$. In

Fig. 3B, the position of phase 1 with respect to pole a is shown for

$$t = 0.25, \text{ for which } \alpha = -0.25$$

Now consider the time-space relations of the m. m. f. waves. By hypothesis the *direct* component of current is maximum at the instant for which the space relations of the m. m. fs. are shown in Fig. 3A, that is at $t = 0$. That is, the instantaneous value of this current is

$$i_d \cos t \tag{1}$$

Thus at that moment, the fundamental[8] A_{1d} and the fifth A_{5d} space harmonics of m. m. f. have the space relations with respect to the poles as shown. Be it

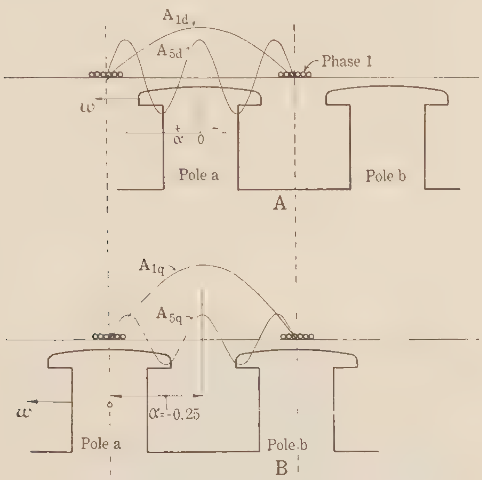


FIG. 3—SPACE AND TIME RELATIONS BETWEEN THE FUNDAMENTAL AND 5TH SPACE HARMONIC OF M. M. F.

A—For direct component of armature current

B—For quadrature component of armature current

remembered that the fundamental is fixed in magnitude and position with respect to the pole, whereas the 5th, like the other harmonics, is rotating with respect to the pole.

The *quadrature* component of current, on the other hand, is a maximum at a *later* time, that is at $t = 0.25$. Thus the instantaneous value is

$$i_q \sin t \tag{2}$$

and the space relations of its corresponding m. m. f. waves *at that instant* are shown in Fig. 3B. But obviously this position is *not the space position which the 5th had at* $t = 0$, since the wave is rotating with respect to the poles. The *quadrature* fundamental, like the *direct* fundamental, is of course stationary with respect to the pole, and of constant magnitude.

To analyze the 5th, it is necessary to obtain an expression for each of the two components of the rotating 5th space sinusoid of m. m. f., namely a_{5d} and a_{5q}. The known characteristics are (a) the amplitude, (b) the space distribution, or position of the rotating wave at one instant, and (c) the speed and direction of rotation. Take the *direct* component first:

(a) amplitude, A_{5d}

(b) maximum value of wave coincides with pole axis at $t = 0$

(c) rotates backward with respect to the armature at $^1/_5$ speed, and with respect to the poles at $^6/_5$ speed, thus at an electrical angular velocity (referred to its own wave length) of six times normal.

The equation for such a rotating wave is

$$a_{5d} = A_{5d} \cos \{ 5 (\alpha + \psi) + 6 t \} \tag{3}$$

at $t = 0$, it is,

$$A_{5d} \cos 5 (\alpha + \psi)$$

But from the assumed boundary condition in Fig. 3A, the space di tribution at $t = 0$ is

$$A_{5d} \cos 5 \alpha$$

Hence $\psi = 0$. Thus the wave is

$$a_{5d} = A_{5d} \cos (5 \alpha + 6 t) \tag{4}$$

Likewise, the 5th rotating m. m. f. wave due to the *quadrature* component of current is

$$a_{5q} = A_{5q} \cos \{ 5 (\alpha + \psi') + 6 t \} \tag{5}$$

At $t = 0.25$, it is

$$A_{5q} \cos \{ 5 (\alpha + \psi') + 1.5 \}$$

which must represent the wave in the particular position shown in Fig. 3B, that is

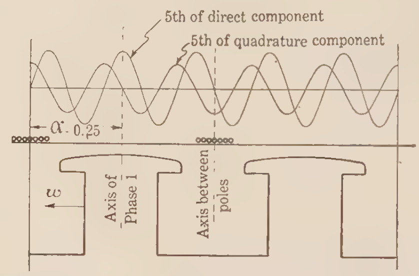


FIG. 4—THE DIRECT AND QUADRATURE COMPONENTS OF THE 5TH SPACE HARMONIC OF M. M. F. AT $t = 0$. EQS. (2) AND (4) RESPECTIVELY

$$- A_{5q} \sin 5 \alpha$$

Thus

$$\cos \{ 5 (\alpha + \psi') + 1.5 \} = - \sin 5 \alpha$$

Hence

$$\psi' = - .05$$

and the equation of the wave is, by (5)

$$a_{5q} = A_{5q} \cos \{ 5 (\alpha - .05) + 6 t \}$$

or

$$a_{5q} = A_{5q} \sin (5 \alpha + 6 t) \tag{6}$$

The waves represented by (4) and (6) are shown in Fig. 4 for the instant $t = 0$.

The stated plan is to resolve each of the two waves (4) and (6) in two pulsating components, stationary with respect to the poles, and then determine the corresponding stationary, pulsating flux waves. Thus, by direct trigonometric transformation, (4) becomes,

$$a_{5d} = A_{5d} (\cos 5 \alpha \cos 6 t - \sin 5 \alpha 6 t)$$

8. The waves as shown are due not only to current in phase 1, but also to currents in the other two phases, the resultant waves of all the currents having, *at that instant*, the same space distribution as the corresponding harmonics produced by phase 1 alone. The magnitudes are different, of course.

which comprises the two stationary pulsating waves

$$a'_{5d} = A_{5d} \cos 5\,\alpha \cos 6\,t \tag{7}$$

and

$$a''_{5d} = -\,A_{5d} \sin 5\,\alpha \sin 6\,t \tag{8}$$

Similarly, (4) becomes,

$$a'_{5q} = A_{5q} \sin 5\,\alpha \cos 6\,t \tag{9}$$

and

$$a''_{5q} = A_{5q} \cos 5\,\alpha \sin 6\,t \tag{10}$$

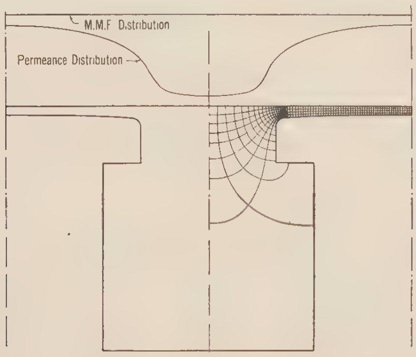


Fig. 5—A—Flux and Permeance Distribution for the Zero Harmonic (Constant m. m. f.), Graphically Determined

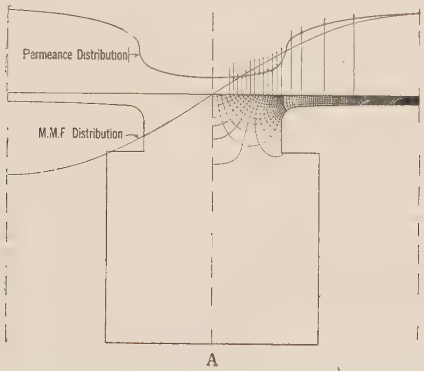
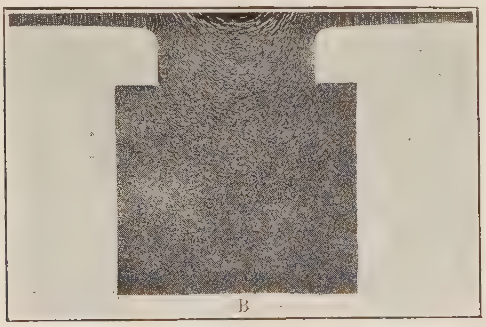


Fig. 6—A—Flux and Permeance Distribution for Fundamental, cos α Distribution of m. m. f., Graphically Determined



B—Flux Distribution by Test

The next step is to obtain the flux waves produced by these stationary, pulsating waves of m. m. f. The product of the m. m. f. at any point along the armature, by the permeance coefficient applying to the magnetic path at that point, gives the flux density at that point.

But the permeance[9] coefficient, as well as the m. m. f., is a function of the space angle α. Although it is different for each harmonic and is in any case a somewhat complicated function of α, it is at least a function which is symmetrical about both the direct and quadrature axes, in all cases of symmetrical salient poles, and can therefore be represented by a Fourier series of even cosines.[10] Fig. 5 shows the distribution of m. m. f., permeance coefficient and resultant flux for the zero harmonic; Fig. 6, the same for the fundamental, cos α distribution of m. m. f.; Fig. 7, for fundamental, sin α distribution of m. m. f.; Fig. 8, for the 5th harmonic, cos 5 α distribution of m. m. f.

These flux distributions were determined in one case

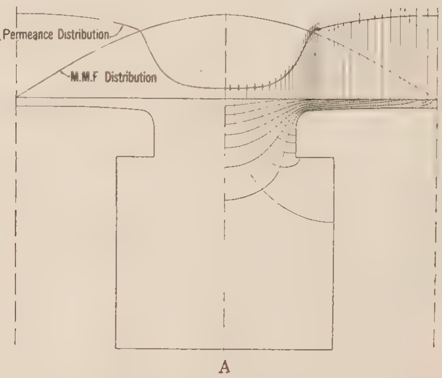
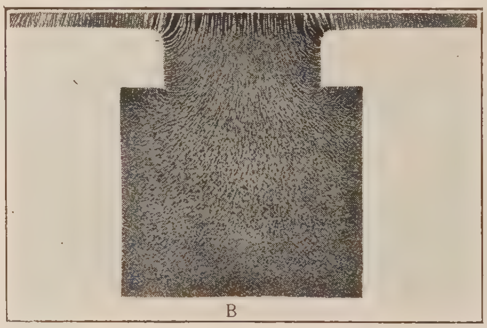


Fig. 7—A—Same as Fig. 6, Except for sin α Distribution of m. m. f.



B—Flux Distribution by Test

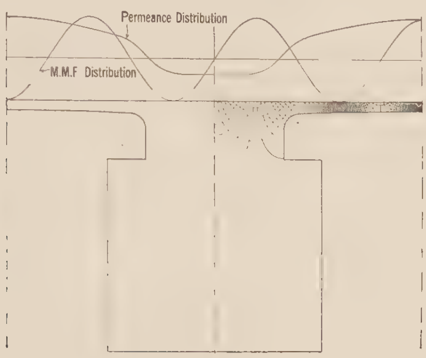
by graphic method, and in the other by test. Also the permeance distributions were determined in one case from the field plot, and in the other, from the curve in

9. Question may be raised whether it is proper to consider the m. m. f. and permeance thus distributed, since the air-gap, in the case of salient poles, is extremely variable, and hence the total m. m. f. indicated at any point may not be entirely consumed in the corresponding permeance; that is, the return path from pole to armature may consume more or less than the path from armature to pole. It is permissible because, over a pole pitch, the distributions are symmetrical, thus giving a corresponding return path in a similar position somewhere within the pole pitch.

10. Even cosines, because a cycle of the resultant permeance wave is of one-pole pitch, thus one-half cycle of fundamental space angle.

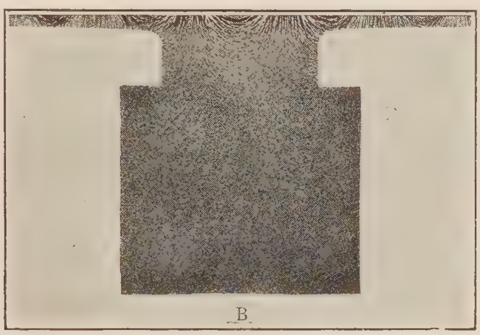
Fig. 10, derived in Appendix B. It will be noted that there is a very reasonable agreement. By appropriate modification of the result for uniform air-gap, the permeance distribution for salient poles may be plotted, as in Figs. 11 and 12, and analyzed.

The two permeance coefficient series, one for the



A

FIG. 8—A—FLUX AND PERMEANCE DISTRIBUTION FOR THE 5TH HARMONIC OF M. M. F. COS α DISTRIBUTION, GRAPHICALLY DETERMINED



B—FLUX DISTRIBUTION BY TEST

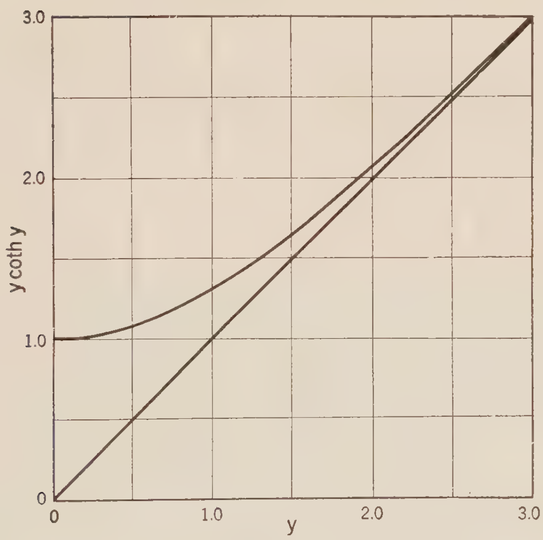


FIG. 10

cosine, the other for the sine distribution of the 5th harmonic m. m. f., are respectively,

$$p^{V}_{c} = p^{V}_{0c} + p^{V}_{2c} \cos 2\,\alpha + p^{V}_{4c} \cos 4\,\alpha + \ldots \quad (11)$$

and

$$p^{V}_{s} = p^{V}_{0s} + p^{V}_{2s} \cos 2\,\alpha + p^{V}_{4s} \cos 4\,\alpha + \ldots \quad (12)$$

the subscript c and s indicating cosine and sine respectively, and the numerally (thus avoiding the appearance

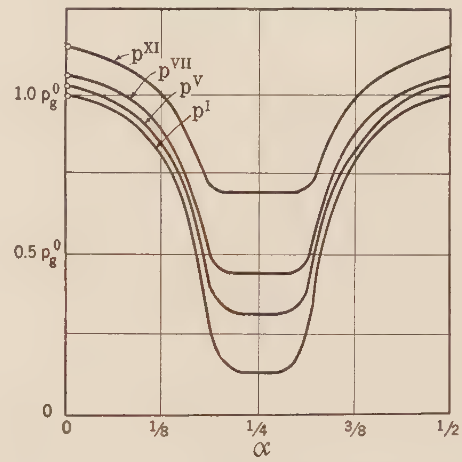


FIG. 11—PERMEANCE DISTRIBUTIONS DETERMINED FROM FIGS 21 AND 22

ANALYSIS OF THESE WAVES GIVES:

$p_0^{I} = 0.66\, p_g^0$	$p_2^{I} = 0.44\, p_g^0$
$p_0^{V} = 0.73\, p_g^0$	$p_2^{V} = 0.37\, p_g^0$
$p_0^{VII} = 0.79\, p_g^0$	$p_2^{VII} = 0.33\, p_g^0$
$p_0^{XI} = 0.94\, p_g^0$	$p_2^{XI} = 0.25\, p_g^0$

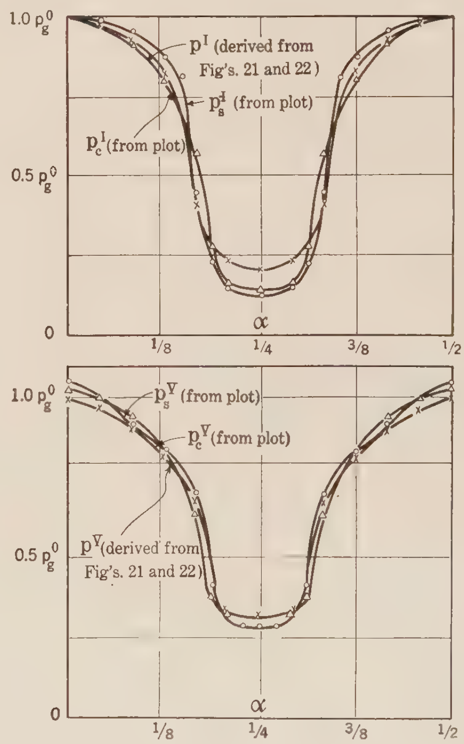


FIG. 12—COMPARISON OF DERIVED AND PLOTTED PERMEANCES FOR 1ST AND 5TH HARMONICS

of an exponent) indicating that the series is for the 5th space harmonic of m. m. f.

The flux waves are, therefore, obtained by multiplying (7) and (10) by (11), and (8) and (9) by (12).

Thus,

$$\beta'_{5d} = \frac{1}{2} A_{5d}[(p^{V}_{4c} + p^{V}_{6c}) \cos \alpha + (p^{V}_{2c} + p^{V}_{8c}) \cos 2 \alpha$$

$$+ (2\, p^{V}_{0c} + p^{V}_{10c}) \cos 5 \alpha$$

$$+ (p^{V}_{2c} + p^{V}_{12c}) \cos 7 \alpha + \ldots] \cos 6\, t \qquad (17)$$

$$\beta''_{5d} = -\frac{1}{2} A_{5d}[(p^{V}_{4s} - p^{V}_{6s}) \sin \alpha + (p^{V}_{2s} - p^{V}_{8s}) \sin 3\alpha$$

$$+ (2\, p^{V}_{0s} - p^{V}_{10s}) \sin 5 \alpha$$

$$+ (p^{V}_{2s} - p^{V}_{12s}) \sin 7 \alpha + \ldots] \sin 6\, t \qquad (18)$$

$$\beta'_{5q} = \frac{1}{2} A_{5q}[(p^{V}_{4s} - p^{V}_{6s}) \sin \alpha + (p^{V}_{2s} - p^{V}_{8s}) \sin 3 \alpha$$

$$+ (2\, p^{V}_{0s} - p^{V}_{10s}) \sin 5 \alpha$$

$$+ (p^{V}_{2s} - p^{V}_{12s}) \sin 7 \alpha + \ldots] \cos 6\, t \qquad (19)$$

$$\beta''_{5q} = \frac{1}{2} A_{5q}[(p^{V}_{4c} + p^{V}_{6c}) \cos \alpha + (p^{V}_{2c} + p^{V}_{8c}) \cos 3 \alpha$$

$$+ (2\, p^{V}_{0c} + p^{V}_{10c}) \cos 5 \alpha$$

$$+ (p^{V}_{2c} + p^{V}_{12c}) \cos 7 \alpha + \ldots] \sin 6\, t \qquad (20)$$

Thus the stationary pulsating 5th space harmonic of m. m. f. a'_{5d}, impressed on the variable (in space) permeance, produces space waves of *flux* of *all* odd harmonics, including the fundamental, there being a definite progression in the subscripts of the permeance constants for the increasing order of the odd space harmonic.

It will be noted that if the corresponding harmonics of (17) and (18), and of (19) and (20) be paired, the result will be that for each space harmonic of the series, there will be two flux waves in space and time quadrature, *but of different amplitude.* Now just as the rotating 5th harmonic m. m. f. wave was resolved into two equal stationary pulsating waves in space and time quadrature, so in the present case the equal components (*i. e.*, two amplitudes equal to the smaller) can be composed into one main rotating wave; and the difference between the amplitudes constitutes a residual, single, stationary, pulsating wave, which can be resolved, according to the well-known scheme, into two equal waves of one-half amplitude, rotating in opposite directions. Thus one of these must rotate with the foregoing main wave, and in space phase with it, and the other alone in the opposite direction.

Thus equations (17) and (18) together contain two rotating *flux* waves for each odd harmonic of space distribution, the speeds of rotation being different for all harmonics; hence a corresponding difference also in the magnitude and order of the harmonic voltages thus generated; likewise, (19) and (20). These flux waves are obtained by pairing the corresponding space harmonics of (17) and (18), and of (19) and (20), and expanding them.[11]

Eqs. (17) and (18) therefore give:

$$\beta_{5d1} = \frac{1}{4} A_{5d}[(p^{V}_{4s} - p^{V}_{6s}) + (p^{V}_{4c} + p^{V}_{6c})] \cos (\alpha + 6\, t)$$

$$+ \frac{1}{4} A_{5d}[-(p^{V}_{4s} - p^{V}_{6s}) + (p^{V}_{4c} + p^{V}_{6c})] \cos (\alpha - 6\, t) \qquad (21)$$

$$\beta_{5d3} = \frac{1}{4} A_{5d}[(p^{V}_{2s} - p^{V}_{8s}) + (p^{V}_{2c} + p^{V}_{8c})] \cos (3\, \alpha + 6\, t)$$

$$+ \frac{1}{4} A_{5d}[-(p^{V}_{2s} - p^{V}_{8s}) + (p^{V}_{2c} + p^{V}_{8c})] \cos (3\, \alpha - 6\, t) \qquad (22)$$

$$\beta_{5d5} = \frac{1}{4} A_{5d}\, [\, (2\, p^{V}_{0s} - p^{V}_{10s})$$

$$+ (2\, p^{V}_{0c} + p^{V}_{10c})\,] \cos (5\, \alpha + 6\, t)$$

$$+ \frac{1}{4} A_{5d}\, [-\, (2\, p^{V}_{0s} - p^{V}_{10s})$$

$$+ (2\, p^{V}_{0c} + p^{V}_{10c})\,] \cos (5\, \alpha - 6\, t) \text{ etc.} \qquad (23)$$

And (19) and (20) give:

$$\beta_{5q1} = \frac{1}{4} A_{5q}[(p^{V}_{4s} - p^{V}_{6s}) + (p^{V}_{4c} + p^{V}_{6c})] \sin (\alpha + 6\, t)$$

$$+ \frac{1}{4} A_{5q}[(p^{V}_{4s} - p^{V}_{6s}) - (p^{V}_{4c} + p^{V}_{6c})] \sin (\alpha - 6\, t) \qquad (25)$$

$$\beta_{5q3} = \frac{1}{4} A_{5q}[(p^{V}_{2s} - p^{V}_{8s}) + (p^{V}_{2c} + p^{V}_{8c})] \sin (3\, \alpha + 6\, t)$$

$$+ \frac{1}{4} A_{5}[(p^{V}_{2s} - p^{V}_{8s}) - (p^{V}_{2c} + p^{V}_{8c})] \sin (3\, \alpha - 6\, t) \qquad (26)$$

$$\beta_{5q5} = \frac{1}{4} A_{5q}\, [\, (\, 2\, p^{V}_{0s} - p^{V}_{10s})$$

$$+ (2\, p^{V}_{0c} + p^{V}_{10c})\,] \sin (5\, \alpha + 6\, t)$$

$$+ \frac{1}{4} A_{5q}\, [\, (\, 2\, p^{V}_{0s} - p^{V}_{10s})$$

$$- (2\, p^{V}_{0c} + p._{10c})] \sin (5\, \alpha - 6\, t) \text{ etc.} \qquad (27)$$

The third subscript is the order of the space harmonic *flux* wave. Thus, β_{5q3} is the 3rd harmonic space flux produced by the 5th space m. m. f. due to i_q.

Consider the meaning of these waves. Each one has an electrical angular velocity of six times normal (referred to its own wave length) with respect to the pole. The wave moves forward if the sign of t is minus; and backward if it is plus[12]. Thus, (25) comprises two waves,

11. They could be obtained also by the scheme used to illustrate the physical meaning of the waves, as in Fig. 7.

12. For instance, in a rotating wave, say (25), sin $(\alpha + 6\, t)$ must equal a constant. That is, $\alpha + 6\, t = C$, and $\frac{d\, \alpha}{d\, t} = -6$. Thus velocity is backward at 6 times normal speed.

one (the first term) rotating backward at six times synchronous speed with respect to the poles, five times speed with respect to the armature; the other, rotating forward at six times speed with respect to the poles, thus seven times with respect to the armature. These waves are of full pole span; hence the former generates a 5th harmonic, the latter a 7th harmonic voltage in the armature conductors. Eq. (**26**) likewise comprises two 3rd harmonic space waves, one forward, one backward, with respect to the pole at 6/3 or two times speed, thus generating in the conductors a 9th and a 3rd harmonic voltage. Similarly, (**27**) comprises two 5th harmonic space waves which generate a fundamental and 11th. Similarly the waves due to the *direct* component 5th, in eqs. (**21**), (**22**) and (**23**) produce corresponding harmonic voltages. It will be noted that the only fundamental voltages resulting from the 5th space harmonic of m. m. f. are those due to the backward rotating 5th and the forward rotating 7th space flux waves it produces. All other space fluxes which it produces give higher harmonic voltages.

It is shown in Appendix B that for the 5th and higher space harmonics of m. m. f., the permeance series for the cosine distribution is approximately—almost exactly—the same as that for the sine distribution. Thus, making the approximation that

$$p^{V}_{ms} = p^{V}_{mc}$$

then all of the waves due to the 5th m. m. f. which produce fundamental voltage are,

$$\beta_{5d5} = A_{5d}\, p^{V}_{0} \cos (5\,\alpha + 6\,t) \qquad (29)$$

$$\beta_{5q5} = A_{5q}\, p^{V}_{0} \sin (5\,\alpha + 6\,t) \qquad (30)$$

$$\beta_{5d7} = \frac{1}{2}\, A_{5d}\, p^{V}_{2} \cos (7\,\alpha + 6\,t) \qquad (31)$$

$$\beta_{5q7} = \frac{1}{2}\, A_{5q}\, p^{V}_{2} \sin (7\,\alpha + 6\,t) \qquad (32)$$

What will be the magnitude and phase of the voltages generated by these waves of flux? In general, voltage is, by definition, *minus* the rate of change of magnetic linkages.[13] Thus

$$e = -\frac{d\,\Omega}{d\,t} \qquad (33)$$

The plan is to change the reference of the rotating flux waves from the poles to the armature; then to resolve each wave into two stationary, pulsating components, involving cosine and sine space distributions. The former will produce linkages with phase 1; the latter will not. The linkages thus obtained may then be applied in (**33**).

For illustration, take (**29**). This 5th harmonic wave moves backward at $^6/_5$ speed with respect to the poles, hence at $^1/_5$ speed with respect to the armature thus giving an angular speed, on its own wave length, equal to normal. Let γ be the space angle measured along the armature surface, and reckoned from the axis of phase 1, Fig. 14. Since at $t = 0$ the armature reference (axis of phase 1) and the pole reference (axis of the pole) coincide, the space distribution with reference to the armature will, at that instant, be the space distribution with respect to the pole. Thus the rotating wave expressed with respect to the armature is,

$$\beta_{5d5} = A_{5d}\, p^{V}_{0} \cos (5\,\gamma + t) \qquad (34)$$

Resolve this by expansion into

$$\beta'_{5d5} = A_{5d}\, p^{V}_{0} \cos 5\,\gamma \cos t \qquad (35)$$

and

$$\beta''_{5d5} = -\,A_{5d}\, p^{V}_{0} \sin 5\,\gamma \sin t \qquad (36)$$

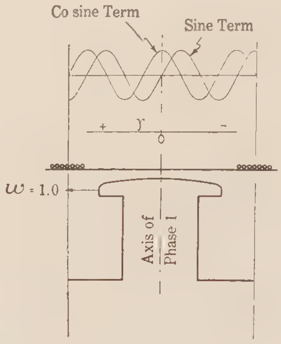


FIG. 14—SPACE REFERENCE ON THE ARMATURE, SHOWING THE POSITION OF THE POLE AND FLUX WAVES AT $t = O$

These are shown in Fig. 14. The flux expressed in (**35**) produces linkages with phase 1, but (**36**) does not. The linkages are

$$\Omega_{5d5} = C_5\, \phi_{5d5} = \frac{A_{5d}\, C_5\, p^{V}_{0}}{5} \cos t \qquad (38)$$

where C_5 is the reduction factor[14] due to pitch, distribution and connection of the coils. The instantaneous voltage, expressed as a fraction of normal voltage, is by (**33**) and (**38**)

$$e_{5d5} = \frac{A_{5d}\, C_5\, p^{V}_{0}}{5} \sin t \qquad (39)$$

But,

$$A_{5d} = \frac{C_5}{5}\, A_{1d}$$

Hence

$$e_{5d5} = \frac{A_{1d}\, C^2_5\, p^{V}_{0}}{25} \sin t \qquad (40)$$

Similarly[15]

13. Linkages of a circuit are understood to be positive when they agree in sign with those produced by a positive current in the circuit.

14. C. A. Adams, bibliography (10).

15. Or these equations may be obtained from the general equations (**58a**) and (**59a**).

$$e_{5q5} = \frac{A_{1q}\, C^2{}_5\, p^{\mathrm{V}}{}_0}{25} \cos t \tag{41}$$

$$e_{5d7} = -\frac{1}{2} A_{1d}\, p^{\mathrm{V}}{}_2 \frac{C_5}{5} \frac{C_7}{7} \sin \tag{42}$$

$$e_{5q7} = -\frac{1}{2} A_{1q}\, p^{\mathrm{V}}{}_2 \frac{C_5}{5} \frac{C_7}{7} \cos t \tag{43}$$

Consider the phase of these voltages. From eqs. (**1**) and (**2**) i_d is a cosine function of time, and i_q a sine function. But e_{5d5}, produced by i_d, is a *plus* sine

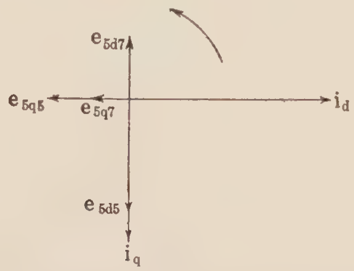


FIG. 15—VECTOR DIAGRAM OF VOLTAGES PRODUCED BY THE 5TH HARMONIC M. M. F.

function. Hence it *lags* a quarter period behind i_d. Similarly, e_{5q5} lags a quarter period behind i_q, which produces it; e_{5d7} leads i_d by a quarter period; and e_{5q7} lags behind i_q by a quarter period. These relations are shown in Fig. 15. It will be noted that e_{qd7} (fundamental) voltage produced by 7th space harmonics of flux (itself produced by the 5th space harmonic of m. m. f.) is a reactive voltage of the same phase relation to the current producing it, as the reactive voltage across a condenser, whereas e_{5d5}, e_{5q5} and e_{5q7} (produced by 5th space harmonics of flux) are of the same nature as the reactive voltage across an inductance. By taking the vector sum of the fundamental voltages due to *all* harmonics[16] (including the fundamental), produced by i_d, and, in addition, the reactive voltages due to the slot and end-winding leakages, the result will be the total reactive voltage produced by i_d, and will thus determine the synchronous reactance x_d for the *direct* component of current. Similarly, x_q is determined for the quadrature component.

The general equations for all harmonics due to the total sine wave (in time) current are given in Appendix A as eqs. (**58a**) and (**59a**).

From these equations the various fundamental voltages[17] have been computed, and are tabulated in Table I, and are shown in Fig. 16 as vectors in relation to the other voltages due to armature current. From these results, the expressions for the reactances are derived in Appendix C.

16. The voltages in Fig. 15 are produced by the 5th space harmonic of m. m. f. alone. There is a similar set of voltages for the 7th, 11th, 13th, 17th, 19th, etc., harmonics of m. m. f.

17. While only the fundamental voltages are derived in detail, equations (**58a**) and (**59a**) contain the harmonics.

It will be helpful to sum up the points thus far established. The general plan, it will be remembered, is to determine, first, all of the component voltages produced by armature currents, such voltages comprising (a) all of those generated by flux emanating from the armature surface, *i. e.*, the air-gap flux, (b) that due to flux crossing the slots, (*i. e.*, slot leakage) and (c) that due to end winding leakage; and, second, all voltages due to current in the field winding; then, by superposition of all significant components, to determine the resultant, which is the terminal voltage. In the foregoing, the voltages due to the air-gap fluxes which are produced by armature current have been determined.

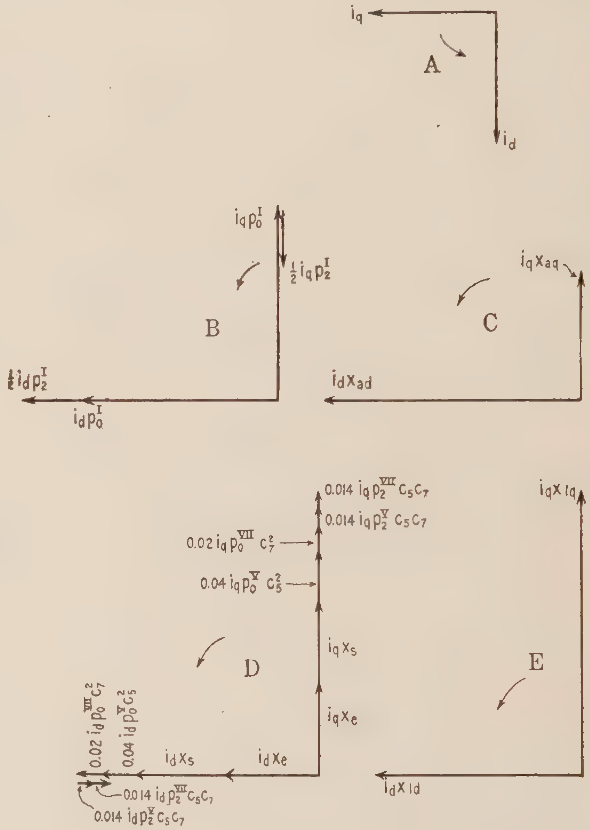


FIG. 16—FUNDAMENTAL VOLTAGES DUE TO ARMATURE CURRENTS

A—Components of armature current
B—Component armature reaction voltages
C—Resultant armature reaction voltages
D—Component leakage reactance voltages
E—Resultant leakage reactance voltages (D and E magnified in scale, compared with B and C)

The voltages due to slot and end winding leakage have been previously determined.[18] Hence all voltages due to armature current are accounted for. In Appendix C the important ones of these are assembled in expressions for reactance.

Field Current Phenomena. The other source of flux is the field current. This current is due to the exciter voltage, assumed to be constant, and to such harmonic

18. Bibliography 8.

voltages as are short-circuited by the field winding. The rotating space harmonic m. m. fs. produced by the armature current are of odd order, and rotate at odd fractions or multiples of synchronous speed with respect to the armature. Hence their electrical angular speed (on the harmonic base) with respect to the field pole and field winding must be of even order; because one times speed is always added to or subtracted from the odd term. For instance, the 5th rotates backward at 1/5th speed with respect to the armature, thus 6/5th with respect to the pole. Hence it generates a 6th harmonic. The 7th rotates forward at 1/7th speed with respect to the armature, hence 6/7th with respect to the poles. Hence it also generates a 6th harmonic in the field winding.

Therefore, the general form of the field current will be a Fourier Series of even harmonic terms, thus

$$I = I_0 \cos 2\,t + I_4 \cos 4\,t + \;.\;.\;.\;. \\ + I'_2 \sin 2\,t + I'_4\, t + \;.\;.\;.\;. \qquad (44)$$

But inasmuch as, in a three-phase machine, the 5th is the lowest order[19] of rotating harmonic m. m. f. (excepting the fundamental), the 6th harmonic must be the lowest order harmonic in the field current. Moreover, since the 7th m. m. f. harmonic also produces only a 6th in the field current, and since the next existing space harmonics are the 11th and 13th, both of which generate a 12th harmonic in the field winding, and next the 17th and 19th, which generate an 18th, it follows that the only harmonics in the field winding are multiples of the 6th.

But these are all of practically negligible magnitudes. While the 6th harmonic ripple may, in rare cases, be detected in the field current under the condition of balanced three-phase currents, and although it does very slightly affect the fundamental voltage, its influence is practically insignificant. Hence only the effects of the average term I_0, which is sustained by the constant exciter voltage, are considered.

The voltage due to the flux produced by I_0 has been adequately treated before.[20] The flux wave thus produced is of the general shape indicated in Fig. 17, and hence contains a fundamental and odd harmonics. The component harmonic waves are, of course, stationary with respect to the poles and therefore generate replica voltage waves in the individual armature conductors. The flux wave is determined, as in Figs. 5, 6, 7 and 8, by graphic field plot from a scale drawing of the armature and field pole.

If there should be a field m. m. f. in the *quadrature* axis, there would be another flux wave produced, symmetrical about that axis, hence containing only odd terms—fundamental and odd harmonics.

Significance of Various Voltages. Consider now some aspects of the various fluxes and voltages. Which of them are important? Which of the fluxes determine the leakage reactance; which, the armature reaction?

Take the harmonic voltages first. These are due, as already explained, to (a) a set of rotating flux waves produced by a sine wave (in time) current; (b) an additional set of rotating waves for each time harmonic in the armature current. In the various sets, the speed of rotation of the respective *space* harmonics (*i. e.*, of the same pole span) is proportional to the order of the time harmonic producing it, and the amplitude is proportional to the amplitude of the time harmonic current; (c) the space harmonics of the field flux; and (d) the effects of permeance waves due to slots.[21]

How important are these harmonic voltages? Some are of no importance because they are of negligible magnitude. This may be due either to small amplitude of the flux harmonic, or to reduction by the connection and space phase of armature conductors. It is well known, for instance, that either a Y connection or $\frac{2}{3}$ coil pitch eliminates the third harmonic; $^4/_5$ pitch, the 5th; $^6/_7$ pitch, the 7th, etc.; and the distribution of coils greatly reduces any which may remain.[22] So in many cases the harmonics may be neglected because they are not appreciable.

Therefore, since the harmonics do not significantly influence the regulation and power relations, principally to be considered here, they will be neglected. If their evaluation, for other purposes, is ever required, the foregoing treatme t, particularly eqs. (**58a**) and (**59a**), constitutes a basis for their determination.

Consider the fundamental voltages. They are due to

(a) fundamental space component of flux due to the *direct* component of armature m. m. f., *i. e., direct* armature reaction.

(b) fundamental space component of flux due to the *quadrature* component of armature reaction.

(c) 5th space harmonic flux,[23] rotating backward at $^1/_5$ speed, and due to the *direct* component of armature current.

(d) 5th space harmonic,[23] rotating backward, and due to the *quadrature* component of current.

(e) two corresponding components, (*i. e., direct* and *quadrature*) of the 7th space harmonics, rotating forward at $^1/_7$ speed.

19. There is an exception to this in the case of a delta-connected machine in which the circulating currents (third harmonic and its multiples) produce space third harmonics of m. m. f. and odd multiples thereof. However, these m. m. fs. rotate at such a speed as to induce in the field winding 6th, 12th, 18th, etc., time harmonics of current.

20. Bibliography 7, and Appendix of 8.

21. This is neglected in the present treatment. It is a different factor from the ripples due to current concentration, the latter being taken into account. The former have been treated by Lyon. See bibliography 7.

22. In most modern alternators the harmonics are practically all thus screened out, leaving the terminal generated voltage almost a true sine wave. Bibliography 10.

23. Each of these, *i. e.*, (c), (d) and (e), comprises two flux components: one due to the 5th space harmonic of m. m. f.; the other, to the 7th. See Table I.

(f) two components of the 11th rotating backward at $^1/_{11}$ speed;[24] and so on.

(g) slot leakage flux produced by both components (*direct and quadrature*).

(h) end-winding leakage flux produced by both components.

(i) fundamental space components of flux due to field m. m. f. in the *direct* axis.

(j) fundamental space component of flux due to field m. m. f. in the *quadrature* axis.

Consider these in detail. The terms (a) and (b)

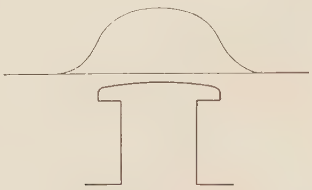


FIG. 17

are the usual vectors of voltage produced by the flux of armature reaction; these are $i_q x_{aq}$ and $i_d x_{ad}$ in diagram, Fig. 18. (i) corresponds to the *nominal* voltage e_d. (j) is an added similar term e_q, Fig. 19,

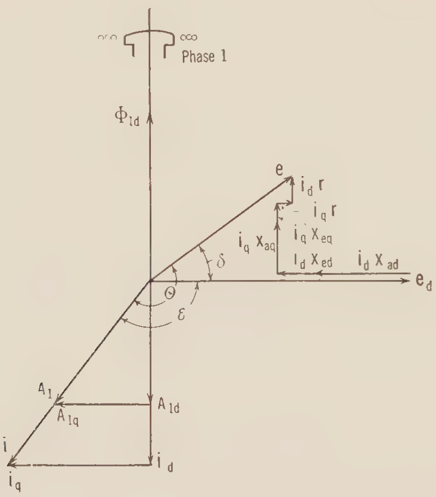


FIG. 18—VECTOR DIAGRAM FROM EQUATIONS. NEGLECTS SATURATION

for the quadrature axis. (g) is the usual slot leakage $i_q x_s$, and $i_d x_s$, Fig. 16D, which is independent of currents in any other slot, and is therefore the same for single or polyphase currents for full pitch coils. They are, however, different for fractional pitch. It may therefore be treated as external reactance,[25] provided the slot contains current of one phase only. Slot reactance is obviously the same for the *direct* and *quadrature* components of current. (h) corresponds to the usual end winding leakage reactance $i_q x_e$ and $i_d x_e$, Fig. 16D. There is some mutual reactance between phases, and hence it is not the same for single-phase and polyphase currents, and hence can not be considered as external reactance. It is here assumed to be the same for the *direct* as for the *quadrature* component of current.

In Appendix C, expressions for the various reactances are derived.

VECTOR DIAGRAMS

From the foregoing, and the results in Appendix C, the vector diagram, neglecting saturation, can be constructed. The diagram, of course, will contain the same quantities as the well-known Blondel diagram, with the rather trifling exception discussed above, regarding the leakage reactance voltages.[26]

From Table I, the voltages due to armature reaction, *i. e.*, to the space fundamentals of flux, are

$$-j A_{1d}\left(p_0^{I} + \frac{1}{2} p_2^{I}\right) = -j\, i_d\, x_{ad}$$

and

$$-j A_{1q}\left(p_0^{I} - \frac{1}{2} p_2^{I}\right) = -j\, i_q\, x_{aq}$$

The voltages due to leakage reactance, derived in Appendix C, are

$$-j\, i_d\, x_{ld}$$

and

$$-j\, i_q\, x_{lq}$$

Taking the fundamental flux ϕ_{1d}, *direct* axis, as the time reference vector, the vector diagram in Fig. 18 is constructed. By the convention adopted in the equations, i_q was taken as lagging with respect to i_d. This corresponds to a *motor* load; hence in Fig. 18, according to the definition, the power-factor angle θ is greater than 90 deg., *i.e.*, > .25. Redrawing Fig. 18 in Fig. 20, the conventional relations are shown, in which i_q is reversed, thus a generator load. Also the reactances are combined, since saturation is in this particular case neglected.

$$x_d = x_{ad} + x_{ld}$$

$$x_q = x_{aq} + x_{lq}$$

The vectors in Fig. 20 are the *induced*, not the consumed, voltages.

Introducing an excitation current in a field winding around the quadrature axis, brings in an additional voltage e_q as shown in Fig. 19. The general power-angle relations are derived in Part II from this diagram. An approximate method, due to Blondel, for taking

24. When irregular armature windings are used, for instance, fractional slots per pole and then additional harmonics occur. These are important since they may create serious vibration in the stator frame; and, in the case of induction motors, may significantly increase the leakage reactance. Their computation is beyond the scope of this paper.

25. The effect of currents of different phases in the same slot, as in fractional coil pitch, is accounted for by appropriate factors in the calculation of slot leakage.

26. In the present treatment these comprise all fundamental voltages except those produced by the two space fundamental flux waves.

saturation into account will be referred to in Part II and also in Appendix D, in which Fig. 20 will be interpreted in terms of the familiar Potier diagram for cylindrical rotor machines.

An idea of relative phase and magnitude of voltages may be obtained from an inspection of Table I. Referring to Fig. 16D, in which the phase relation of the various vector voltages of Table I is shown,[27] it will be noted that the only ones which do not have the same phase relation with respect to the current which causes them, are those which involve products $C_5\, C_7$, $C_{11}\, C_{13}$, etc.—that is, those terms in which a flux of one space order is produced by m. m. f. of another space order.

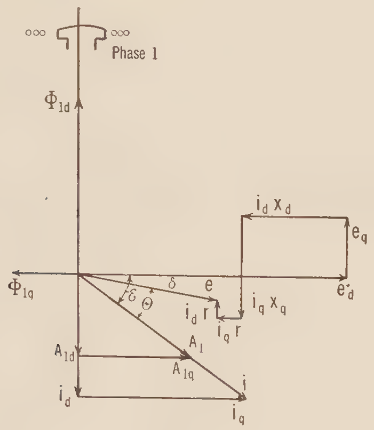


FIG. 19

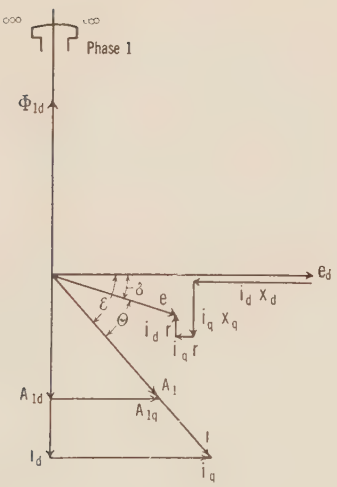


FIG. 20—VECTOR DIAGRAM—USUAL CONVENTIONS

The diagrams show nothing above the 7th, since the next term involves the 11th and 13th, and is entirely negligible. They are, in other words, only those terms which involve second harmonic permeance coefficients for m. m. f. space orders > 1.0, such as p_2^{V}, p_2^{VII}, etc. They are given in eq. (7c) Appendix C. It will be observed in Fig. 16D that the only such terms are

$$0.014\, i_d\, p_2^{V}\, C_5\, C_7$$
$$0.014\, i_d\, p_2^{VII}\, C_5\, C_7$$

27. In the diagram, currents are substituted for corresponding armature reactions.

TABLE I

FUNDAMENTAL VOLTAGES

A. Due to Direct Component of Armature Current.

n	m	k_n	Order of Flux Wave	Amplitude and Phase of Fundamental Voltages
1	0	1	1	$-j\, A_{1d}\, p_0^{I}$
1	2	1	1	$-j\, \frac{A_{1d}\, p_2^{I}}{2}$
5	0	−1	5	$-j\, \frac{A_{1d}\, C^2_5\, p_0^{V}}{25}$
5	2	−1	7	$+j\, \frac{A_{1d}\, C_5\, C_7\, p_2^{V}}{70}$
7	0	1	7	$-j\, \frac{A_{1d}\, C^2_7\, p_0^{VII}}{49}$
7	2	1	5	$+j\, \frac{A_{1d}\, C_7\, C_5\, p_2^{VII}}{70}$
11	0	−1	11	$-j\, \frac{A_{1d}\, C^2_{11}\, p_0^{XI}}{121}$
11	2	−1	13	$+j\, \frac{A_{1d}\, C_{11}\, C_{13}\, p_2^{XI}}{286}$
13	0	1	13	$-j\, \frac{A_{1d}\, C^2_{13}\, p_0^{XIII}}{169}$
13	2	1	11	$+j\, \frac{A_{1d}\, C_{13}\, C_{11}\, p_2^{XIII}}{286}$

B. Due to Quadrature Component of Armature Current

n	m	k_n	Order of Flux Wave	Amplitude and Phase of Fundamental Voltages
1	0	1	1	$-j\, A_{1q}\, p_0^{I}$
1	2	1	1	$+j\, \frac{A_{1q}\, p_2^{I}}{2}$
5	0	−1	5	$-j\, \frac{A_{1q}\, C^2_5\, p_0^{V}}{25}$
5	2	−1	7	$-j\, \frac{A_{1q}\, C_5\, C_7\, p_2^{V}}{70}$
7	0	1	7	$-j\, \frac{A_{1q}\, C^2_7\, p_0^{VII}}{49}$
7	2	1	5	$-j\, \frac{A_{1q}\, C_5\, C_7\, p_2^{VII}}{70}$
11	0	−1	11	$-j\, \frac{A_{1q}\, C^2_{11}\, p_0^{XI}}{121}$
11	2	−1	13	$-j\, \frac{A_{1q}\, C_{11}\, C_{13}\, p_2^{XI}}{286}$
13	0	1	13	$-j\, \frac{A_{1q}\, C^2_{13}\, p_0^{XIII}}{169}$
13	2	1	11	$-j\, \frac{A_{1q}\, C_{13}\, C_{11}\, p_2^{XIII}}{286}$

In the above terms, $A_{1d} = i_d$ and $A_{1q} = i_q$. See "notation."

These are *reversed* with respect to the other voltages produced by i_d. The corresponding terms produced by i_q are,

$$0.014\, i_q\, p^{V}{}_2\, C_5\, C_7$$
$$0.014\, i_q\, p_2{}^{II}\, C_5\, C_7$$

which *add on* to corresponding voltages produced by i_q.

What about the magnitude? The product $C_5 C_7$ may be of any value between zero and a maximum value = 1.0 for a three-phase machine. It is zero if the coil pitch is either $^4/_5$ or $^6/_7$, and greatly reduced for other pitches.[28] It is greatly reduced also by coil distribution.[29] The permeance coefficients $p_2{}^{V}$ and

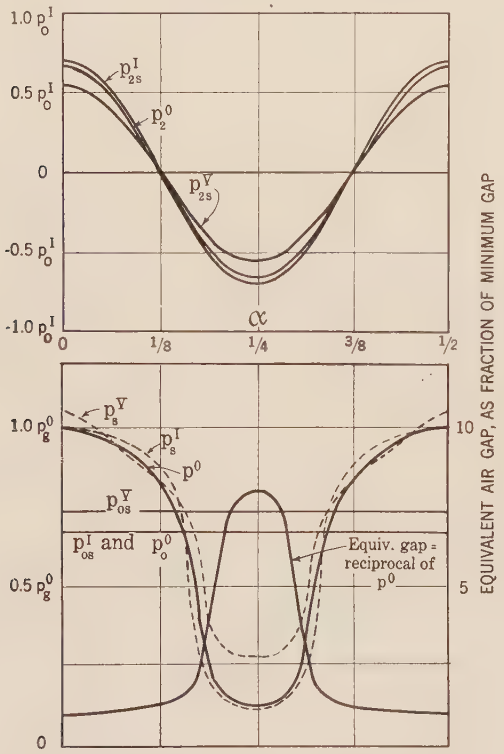


FIG. 21—PERMEANCE DISTRIBUTION DETERMINED FROM FIELD PLOTS. ALSO EQUIVALENT AIR-GAP

$p_2{}^{VII}$ are of the order of 50 per cent of $p_0{}^{I}$. Thus the maximum possible value of each term is of the order of ½ of one per cent of the armature reaction voltage due to i_q or to i_d. This would give a maximum variation in leakage reactance voltage with pole position, of the order of ± 1 per cent of the armature reaction voltage; and in many cases, on account of fractional pitch, etc., it would be practically zero. Therefore the conclusion is that in many salient pole machines the variation in leakage reactance with pole position is entirely negligible, and is of small magnitude in any case approaching the usual design practise.

PRACTICAL APPLICATION OF RESULTS

The application of the method given here requires numerical data for the zero and second space harmonic of permeance for each significant harmonic m. m. f. The harmonic m. m. fs. are easily computed, and are all expressed in Table I in terms of the fundamental m. m. f. component. But the permeance coefficients must be determined from field plots[30] such as shown in Figs. 5, 6, 7, 8 and 9. From such plots, the permeance curves are determined and analyzed to obtain the required value of the average and the second harmonic coefficients. Partial analysis of these particular plots is shown in Fig. 21.

TABLE II

COMPARISON OF PERMEANCES OBTAINED DIRECTLY FROM FIELD PLOTS, AND DERIVED FROM FIGS. 10 AND 21.

	Values from plots	Values Derived from Figs. 10 and 21
$p_{0c}{}^{I}$	$0.67\ p^0{}_g$	$0.66\ p^0{}_g$
$p_{0s}{}^{I}$	$0.67\ p^0{}_g$	
$p_{2c}{}^{I}$	$0.43\ p^0{}_g$	$0.44\ p^0{}_g$
$p_{2s}{}^{I}$	$0.47\ p^0{}_g$	
$p_{0c}{}^{V}$	$0.74\ p^0{}_g$	$0.73\ p^0{}_g$
$p_{0s}{}^{V}$	$0.73\ p^0{}_g$	
$p_{2c}{}^{V}$	$0.38\ p^0{}_g$	$0.37\ p^0{}_g$
$p_{2s}{}^{V}$	$0.37\ p^0{}_g$	

$$\frac{\text{min. gap}}{\text{pole pitch}} = 0.02 \qquad \frac{\text{pole arc}}{\text{pole pitch}} = \frac{2}{3}$$

$$\frac{\text{max.}}{\text{min.}}\ \text{gap} = 1.5 \qquad p_g{}^0 = 1.5\, p_0{}^{I}$$

In order to avoid having to plot, as above, the flux distribution for each significant harmonic, including the fundamental, an approximation is made as follows: A plot is made for the zero harmonic, as in Fig. 5, which results are shown also on Fig. 21. In addition the latter shows a curve of "equivalent air-gap," taken as the reciprocal of the permeance for the zero harmonic. From this and the curve in Fig. 10, derived in Appendix B, the permeance curves for any harmonic can be obtained, as in Fig. 11. These are then analyzed for the zero and second harmonic. The results thus obtained for the particular case here illustrated are compared in Table II with those obtained directly from the plots and are also compared in complete curves in Fig. 12. It will be noted that the agreement is very satisfactory. The only discrepancy worth noting is between $p_{2c}{}^{I}$ and $p_{2s}{}^{I}$, which are, from plots, respectively 0.43 and 0.47. The value derived from Figs. 10 and 21 is 0.44.

28. Of course it would be zero also for a pitch of either $^2/_5$ or $^4/_7$, etc.

29. C. A. Adams, Bibliography 10.

30. Comprehensive treatments of flux plotting are being prepared by engineers of the General Electric Company, for presentation at an early date.

The above simplifying assumptions are fully discussed in Appendix B.

The general plan, therefore, is to obtain a permeance curve for the zero harmonic for the machine under consideration, and from that, the "equivalent air gap" curve. Then with the aid of Fig. 10, plot a group of curves as in Fig. 11. An analysis of these will give the required $p_0{}^n$ and $p_2{}^n$.

Research Relations Between Engineering Colleges and Industry

BY W. E. WICKENDEN[1]

Member, A. I. E. E.

IN our present easy-going attitude toward language, we are tempted to use the word "research" to mean so many things that we have no word left to mean research. The effort to sell a research program to industry has induced us to translate the word into such unmistakably practical terms as "in a word it is invention," to quote a recent official pamphlet.

In the present discussion it is probably safe to assume that we are dealing only incidentally with disinterested pioneer work in the realm of pure knowledge, which is the scientist's calling. Engineering is always utilitarian and concrete, and most engineers abandoned the alternative of becoming physicists, chemists or mathematicians in order to become engineers. This observation holds for professors as well as practitioners. Every professor of engineering worthy of the title, however, is qualified to investigate engineering problems involving elements of novelty which call for extended observation, refined technique, and a resort to fundamental principles. The indications are that both the men and facilities available for these purposes in the engineering colleges are now being utilized very inadequately, to the detriment of both industry and education.

A fairly complete survey of the engineering colleges in the United States shows that not less than 58 have organized arrangements for research, at least on paper. Included in this number are 41 institutions which have organized plans through which the services of the engineering staff are made available in consulting capacities to industries, public service utilities and others. If we include those institutions in which research is fostered on a purely individual basis, the total rises to 110.

The total expenditures of the organized research departments are not less than $1,250,000 per annum and may reach as high as $1,500,000. Of such expenditures in the academic year 1924-'25, approximately 11 per cent represented direct appropriations for research by the several states, 40 per cent funds allotted by the colleges from their general funds, and 49 per cent funds derived from outside sources, principally from public, professional and industrial organizations.

At least 34 institutions have full-time research staffs, with between 250 and 300 men so engaged. To this number may be added about 350 more who render part-time research service for definite compensation and about 200 who give part-time service in organized departments without special compensation. The number engaged on a purely individual basis is difficult to estimate.

Impressive as these totals are, it must be remembered that there are two corporations in the electrical industry which spend on research more than double the total outlay of the engineering colleges and that at least two in other fields exceed the total of the colleges. Organizations at this end of the industrial scale are unlikely to turn to the engineering colleges to get their problems solved. Big business can probably be induced to give support to organized investigation in engineering colleges only on the plea that such activity is necessary in order to maintain the proper setting and staff for the training of the grade of engineers big business requires. Pure research rather than engineering investigation seems likely to get the bulk of the financial assistance from this source, and it seems probable that it will be disbursed through some intermediary or clearing house, instead of passing directly to individual colleges or professors. The present campaign of the National Academy of Sciences for a national research endowment, under the leadership of Mr. Herbert Hoover, is working successfully on this principle.

At the other end of the scale are innumerable, small units of industry which live from balance sheet to balance sheet, with no consciousness of research needs and little margin for the support of research activities. Such organizations occasionally meet acute problems outside the scope of their normal routine and staff. When these emergencies call for investigation, a college professor or laboratory staff may fit the need admirably, but is this not first aid rather than research?

Many of these smaller units of industry are concerned with the traditional arts rather than with the applications of modern science. They are likely to remain deaf to any appeal to support research for the sake of repay-

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ing their debt to science or for the sake of maintaining a wide margin between pure knowledge and practical invention. It is just these industries, however, which are most apt to be handicapped by the decline of sporadic invention and likely to profit most relatively, from an adequate program of research. Support for such investigation is not to be expected from the single units of such industries, but their state and national trade associations are the natural agencies to foster such activities. There are attractive possibilities of dividends in the form of better methods, economies and more exact control in the present state of the art. Research, looking in advance of the present art, is a form of mutual insurance covering the risks of supersession or revolutionary changes in the art.

A recent report of the Babson Statistical Organization announced that an English factory was testing out the production of a flexible, colorless, resilient, non-inflammable glass of organic origin. It went on to say:

> "The point of this letter, however, is not only about glass. This is but one of numerous far-reaching discoveries which have recently been reported. We believe that business is entering an era of the most rapid and revolutionary changes in the chemistry and physics of manufacturing. To those who are quickest in taking advantage of such discoveries, they present unlimited opportunities, but the manufacturer, merchant or investor who is asleep to these changes will be hurt.
>
> "The time has passed when advertising alone will get sales. The two best salesmen today are 'a better product' and 'a cheaper way of making it.' Research opens the way to both. Furthermore, since the most deadly competition is not between concerns, but between industries, we urge clients to combine their energies with others in the same line of business. This saves duplication of efforts, leads to maximum results and keeps one best informed about all impending developments. Make use of the help which the United States Bureau of Standards at Washington stands ready to give you, and also that of other technical organizations of high standing. Cease worrying about gaining the temporary advantage of exclusive patents, and combine your resources in the way that will do most to permanently help your industry."

It is significant that the occasion which brought the above report to the writer's desk was a request from its authors for a complete list of the engineering colleges with facilities for organized research in cooperation with industry. The writer is strongly of the opinion that trade and industrial associations offer by far the most promising agencies through which to promote industrial cooperation with the colleges in engineering research. The support of such activities by individual corporations is apt to be sporadic while trade associations can effectively maintain a continuing relation. The results of work supported by individual corporations are apt not to be widely disseminated or used. A good deal of such support is frankly on a courtesy basis, without a vital interest in its effectiveness or utilization, and with little genuine collaboration between the college and the industry.

A trade association, administering its funds in trust for its constituency and genuinely concerned to show a good return for the investment, provides an excellent medium for the joint shaping of research projects and a widely ramified channel through which to disseminate results. It would seem that the most fruitful result may be expected when a trade association concentrates its cooperative program at a single college, or at a small group of institutions at most. Such work ought not to be located on a courtesy basis or split up on a political basis, but should seek to capitalize distinctive advantages of men, plant and environment. There is a definite loss when such resources are spread over many institutions as a fairly ineffectual mist, when they might be concentrated into a fairly powerful stream. In this respect the European situation is far better ordered than our own. The policy of concentrating resources abroad has led to the upbuilding of a group of notable and distinctive research centers which are the principal factor in attracting and holding to educational and research work the outstanding authorities in the several fields. The result has been to give the several institutions an individuality quite unknown among us.

The writer does not feel that the colleges can rest their case for industrial backing for their research programs on the needs of the colleges or on an assumed sense of obligation on the part of industry to see that the colleges obtain the men, money and facilities needed to do their best work. The industries recognize these obligations rather vaguely, and when confronted by the competing pleas of 100 to 150 institutions are justified in feeling rather helpless. The Babson report, however, speaks in the tongue which industry understands and to which it responds.

The work being done at Cincinnati in cooperation with the Tanners' and the Lithographers' national organizations, the power brake studies at Purdue in cooperation with the American Railway Association, the studies in warm air heating and ventilating at Illinois, and the great project of the Portland Cement Association in association with Lewis Institute are worthy examples of adequately supported, nationally backed and effectively concentrated research programs, involving real collaboration between colleges and industries and leading to results of great significance and value.

A 7,500,000-c. p., 900-watt searchlight is being installed on the Broadmoor Hotel's Summit House on Cheyenne Mountain, overlooking Colorado Springs and Manitou, Colorado. The highest beacon in the world is said to be the 5,000,000-c. p. aviation light on Sherman Hill, Wyoming, 8600 ft. above sea level.

A Flux Voltmeter for Magnetic-Tests

BY G. CAMILLI[1]

Associate, A. I. E. E.

Synopsis.—*A voltmeter is described for a-c. circuits the voltage indications of which are directly proportional to the maximum flux density, regardless of the wave shape of the voltage. While the instrument is suitable for many varieties of magnetic tests, its most important application is to the reduction of transformer core-loss measurements to sine-wave basis. Test data indicate excellent accuracy for the meter in this application in comparison with other schemes or outfits used at the present time for that purpose. Losses determined by this new meter are, in general, appreciably larger than those determined by the older methods.*

The new meter makes it unnecessary to use, for reliable results, large generators to reduce the wave distortion caused by transformer excitation loads, and permits the use of any generator that will carry the load thermally.

Introduction

THIS paper describes a voltmeter for a-c. measurements designed so that its indications are directly proportional to the maximum value of a-c. magnetic flux regardless of wave shape. It is graduated in terms of equivalent effective sine-wave voltage, so that at any wave shape the maximum magnetic flux is the same as the maximum value of sine-wave flux generating a sine-wave voltage of the same effective value as the indication of this voltmeter. The instrument is particularly useful in core-loss measurement and for exploring alternating-flux magnetic networks. It is useful also for the determination of the form factor of a-c. voltages, and, with slight modifications, the form factor of alternating currents.

It is recognized that certain circuit characteristics are functions of the maximum value of the alternating wave. For instance, hysteresis loss and also magnetizing current to a large extent are functions of the maximum flux density, not functions of r. m. s. values of current, voltage or flux. The problem of measuring this maximum flux has not been satisfactorily solved by other methods though ballistic galvanometers and core-loss voltmeters or correction outfits have been developed and used for the purpose. The ballistic galvanometer is not well suited to a-c. measurements, and core-loss voltmeters have serious limitations as will be pointed out later.

The instrument developed by the writer for this purpose, called a flux voltmeter, consists essentially of a rectifier in series with a d-c. voltmeter. Across these two in series is impressed the voltage which is generated in a coil surrounding the core under test in which the alternating flux exists. Under this condition, the voltmeter indications, as will be proved later, are proportional to the maximum magnetic flux in the core.

Theory of the Instrument

The principles underlying the functioning of the flux voltmeter are two:

First, in an a-c. circuit, the maximum alternating flux density is proportional to the arithmetic average value of the reactive voltage drop regardless of the wave shape of the voltage, provided the wave does not cross the zero line more than twice per cycle.

Second, if an alternating voltage is rectified without changing the wave shape, and is impressed on a d-c. voltmeter, the meter indication is proportional to the arithmetic average value of the rectified wave which is the same as the arithmetic average value of the unrectified a-c. wave.

The proof of the first theorem is as follows:

Let e be the instantaneous voltage consumed in the inductance of a circuit, and ϕ the flux associated with that circuit. By elementary theory,

$$e = K \frac{d\,\phi}{d\,t} \tag{1}$$

where K is constant of the circuit. It follows from (**1**) that

$$e\,d\,t = K\,d\,\phi$$
$$\int e\,d\,t = K \int d\,\phi$$

The integral of $d\,\phi$ is obviously the change in the flux; and its maximum value, that is, the maximum change in flux, is obtained by finding the maximum change in the integral of $e\,d\,t$. Referring to Fig. 6, the integral of $e\,d\,t$ is the area of the voltage wave (alternately positive and negative, plus a constant of integration), and the maximum change in $\int e\,d\,t$ is the area of half a cycle of the voltage wave. Thus,

$$\int_{t_1}^{t_2} e\,d\,t = K \int_{\phi\ \text{lower limit}}^{\phi\ \text{upper limit}} d\,\phi$$

$= K$ times the maximum change in flux.

The area of one-half cycle of the voltage wave may be also determined, however, if we know the average voltage, by the equation,

$$\int_{t_1}^{t_2} e\,d\,t = \text{area of half-cycle}$$

$$= e_{avg}\,(t_2 - t_1)$$

The maximum change in flux is therefore proportional to e_{avg} since $(t_2 - t_1)$ is a constant, being the duration of half a cycle dependent only on the frequency of the circuit. Since, also, the flux density is proportional to the total flux, the maximum a-c. flux

1. Transformer Engineering Department, Pittsfield Works, General Electric Company.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

density, B_{max}, must be proportional to the maximum total a-c. flux, ϕ_{max}, and thus we have,

B_{max} is proportional to e_{avg}.

The factor of proportionality is taken care of as follows: the meter scale being graduated in terms of effective sine-wave voltage, it follows that the alternating flux density in the circuit under test corresponds to an effective sine-wave voltage of the same equivalent value as the indication of the flux voltmeter. In other words, for any given wave shape of voltage, the flux voltmeter indicates its equivalent sine-wave value, which would cause the same maximum flux or

FIG. 1

flux density. On pure sine-wave voltage, the indications of the flux voltmeter are naturally identically the same as those of an ordinary r. m. s., a-c. voltmeter. In fact, the meter is calibrated in this way.

The reason for the limit to wave distortion mentioned above, namely, that the wave must not cross the zero

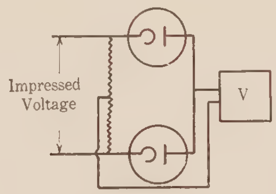

FIG. 2

more than twice per cycle, may be understood as follows.

Considering the positive half cycle of the voltage wave, assume that this dips through the zero and has a negative portion. The positive portions of the half-cycle will add to the flux in accordance with the integral of $e\,d\,t$, and the negative portion will subtract by the

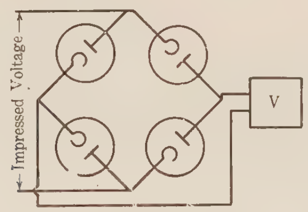

FIG. 3

same integral. Since the flux voltmeter rectifies the entire wave, this small negative portion will also be rectified and instead of reducing the voltmeter reading will increase it. The reading of the voltmeter, therefore, even though it still represents the arithmetic average of the voltage wave, will not truly represent the maximum of the flux wave. This limitation, however, is hardly a handicap because it is almost inconceivable that a commercial voltage wave could be so distorted as to cross the zero more than twice per cycle.

Description of the Instrument. The practical construction of an instrument to meet these requirements is quite simple. Vacuum tubes are used for rectification, and a high-resistance, d-c. voltmeter to read the arithmetic average value of the rectified wave.

A diagrammatic sketch of the simplest possible con-

FIG. 4

struction is shown in Fig. 1 which shows a single rectifier tube in series with a d-c. voltmeter. The voltage to be measured is impressed across the voltmeter and rectifier in series; and the meter indication is then proportional to the integral of the impressed voltage.

Although the scheme of Fig. 1 is extremely simple, it suffers from two disadvantages: first, due to half-wave rectification the frequency of the pulsations of the rectified wave is one-half of that of the completely rectified wave, and it was observed that with 25-cycle impressed voltage, the needles of some voltmeters would vibrate like a frequency-meter reed. The second disadvantage is that with half-wave rectification the deflection of the meter is reduced to one-half. To increase the deflection would require a reduction in the resistance of the meter to one-half, double the current, all double the losses,—all of which would be undesirable.

The scheme shown in Fig. 2 using two tubes and an auto-transformer for rectifier yields full-wave rectification and better characteristics in general, except that the exciting current drawn by the shunt auto-

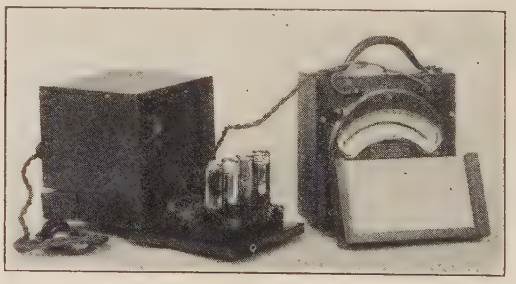

FIG. 5

transformer might be objectionable, especially when instrument transformers are used.

The connection found most satisfactory is shown diagrammatically in Fig. 3, consisting of a four-tube, full-wave rectifier in combination with a d-c. voltmeter.

The instrument used for the investigations described below was constructed in accordance with the scheme of Fig. 3. Fig. 4 is a reproduction of a photograph of the outfit, showing the rectifier and voltmeter in separate cases, although some units now under construction incorporate the rectifier and voltmeter in one case. Fig. 5 shows the contents of the rectifier unit,—four vacuum tubes and one filament-current transformer. The purpose of the filament-current transformer is to obtain the necessary filament current from the lighting circuit instead of from the circuit under test. To draw this current from the circuit under test would be doubly objectionable: it would load the potential transformers in the circuit unnecessarily and reduce their accuracy, and it would change the calibration of the instrument with varying load voltage. Supplying the filament excitation from a lighting circuit eliminates both these difficulties, especially the latter, inasmuch as variations of the voltage of the lighting circuit, within the range of 110 to 125 volts, have no sensible effect on the calibration of the instrument.

The voltmeter is graduated in terms of equivalent effective r. m. s. sine-wave voltage, so that the maximum flux density in the core under test is the same as the maximum flux density for an r. m. s. sine-wave voltage of the same value as that indicated by the flux-voltmeter.

The constants of the tubes, meter and transformer are as follows:

Fig. 6

Fig. 7

Fig. 8

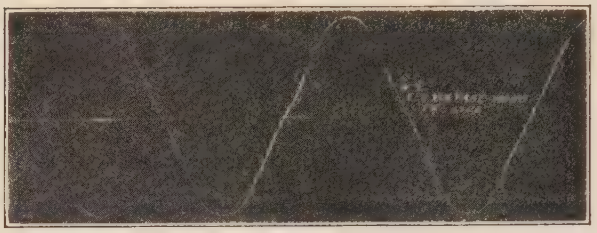

Fig. 9

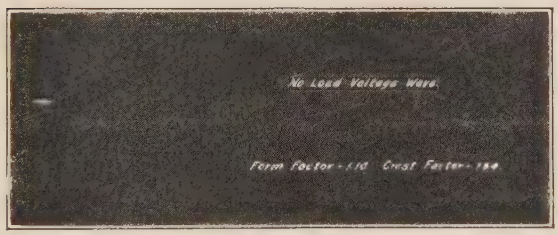

Fig. 10

Fig. 11

Fig. 12

Tubes: Radio Corporation of America type, *U X*-120 tubes, well known to the radio public. Although this tube is of the three-element type, its grid and plate are connected together so as to act as a single electrode for rectification. The resistance of the tube in this connection is of the order of 5000 ohms. Rated filament voltage three volts, filament current 0.125 amperes.

Transformer: primary rated 110—125 volts, 25—60 cycles; four secondary windings, one for each tube, each rated 3—3.75 volts.

Voltmeter: d'Arsonval type, d-c. voltmeter, resistance 178,000 ohms. Scale 150 volts, equivalent sine-wave voltage.

Effect of Tube Resistance

A voltmeter circuit always has a large series resistance incorporated within the voltmeter box. Tube

resistance, therefore, not only is not a handicap but is a useful element, furnishing some of the desired resistance to the voltmeter circuit. In fact, were it not for the variability of tube resistance, it would have been desirable to use sufficiently high-resistance tubes to replace and eliminate all other series resistance. It is known that tube resistance varies with plate voltage, however, and therefore the tubes were chosen so as to make their resistance a small fraction of the total resistance of the voltmeter circuit. In the outfit described above, the tube resistance is only about five per cent of the total resistance, and therefore any little variations in the tube resistance are imperceptible in the total resistance.

Accuracy of the Flux-Voltmeter

The accuracy of the flux voltmeter in measuring the average value of any given voltage was tested both by the writer and by the Bureau of Standards and in both instances was found to be very satisfactory. Our tests consisted of (a) form-factor tests checked by oscillographic analyses, and (b) tests of application to core loss measurements.

Form-Factor Measurements

The form factor of a wave is defined as the ratio of the r. m. s. value of the wave to its arithmetical average value. Since ordinary a-c. voltmeters give the r. m. s. value, and the flux voltmeter the arithmetical average value, the form factor of a given voltage wave may be obtained by means of these instruments. The value so obtained may be checked oscillographically by computing from an oscillographic record of the wave both its effective and its average values in accordance with well-known methods. Since the flux voltmeter is graduated in terms of equivalent effective sine-wave volts, and since the form factor of a sine wave is 1.11, it follows that the form factor of a distorted wave is:

$$\text{form factor} = 1.11 \times \frac{\text{a-c. voltmeter reading}}{\text{flux-voltmeter reading}}$$

The foregoing method of test and checking was applied to seven different wave shapes obtained on different generators under different conditions of loading, with results as follows:

Items	Exciting Current Load on the Generator	Form Factor By Oscil.	Form Factor By Flux Voltmeter	Figures
	Per Cent			
1	20	1.21	1.231	6
2	7	1.13	1.128	7
3	30	1.148	1.149	8
4	6	1.128	1.122	9
5	55	1.18	1.18	10
6	18	1.14	1.15	11
7	2.2	1.13	1.115	12

Those who are familiar with oscillographic analyses will appreciate the great difficulty of obtaining precise results. In view of this fact, and also in view of the possible small errors of the a-c. voltmeter used, the foregoing tests may be considered excellent commercial checks on the commercial accuracy of the flux voltmeter. The instrument is really much more precise than these tests seem to indicate, as the Bureau of Standards tests show.

The analyses of the oscillograms were made by a different person who had no knowledge of the form factor obtained by the flux voltmeter, in order that the observations might be unbiased.

Measurement of Transformer Core Loss

The Institute rules provide that the efficiency rating of transformer shall be based on sine-wave operation. Although certain classes of transformer losses, such as the ohmic loss of the conductor, are not affected appreciably by ordinary variations in wave shape, it is known that core loss is seriously affected by the wave shape of the impressed voltage. Since it is difficult to obtain sine-wave voltage on a commercial scale for the testing of transformers, particularly for the condition of exciting current loads which tend to distort the generator voltage, some scheme that will reduce core-loss tests to a sine-wave basis is a necessity. The flux voltmeter was developed primarily for this purpose. The graduation of the scale in terms of equivalent effective sine-wave voltage is particularly useful for this purpose.

The principle of the application of the flux voltmeter to core-loss measurement is based on the fact that if the rated excitation voltage is set by the flux voltmeter at the rated frequency, the maximum flux density in the core corresponds to the rated sine-wave voltage excitation, even though the actual impressed voltage may be badly distorted.

The maintenance of the correct rated maximum flux density in the core by this means assures that the hysteresis loss of the core will correspond to the rated sine-wave voltage, because hysteresis depends on the maximum flux density.

Aside from the hysteresis loss, a core has also eddy-current losses.

Comparing the two types of losses we find that, in general,

(a) The eddy-current loss in laminated transformer cores is much smaller than the hysteresis loss, the eddy-current loss being of the order of one-quarter of the hysteresis loss. This difference in magnitude emphasizes the much greater importance of obtaining the hysteresis loss correctly than of obtaining the eddy-current loss correctly.

(b) While hysteresis loss varies as a complicated function of the density, the eddy-current loss varies substantially as the square of the effective r. m. s. voltage. So by means of the flux voltmeter we obtain the hysteresis loss correctly, and by means of an ordinary r. m. s. voltmeter we are able to make correction for the eddy-current loss.

(c) For a given line of sheet steel, the hysteresis loss per pound may vary a great deal depending on the annealing process and handling, but the eddy-current loss is relatively very slightly affected by these factors. This means that the eddy-current loss of a line of steel may be considered fairly constant without serious error, and hence, calculated corrections applied for it, when necessary, as described below.

When the excitation voltage is set by the flux voltmeter, the desired maximum flux density, and hence the correct hysteresis loss, is obtained. If the voltage wave is distorted, however, the a-c., r. m. s. voltage will be different from the flux voltmeter voltage, and therefore the actual eddy-current voltage under test will be different from that corresponding to the rated sine-wave voltage in the ratio

$$\frac{\text{True eddy loss}}{\text{Observed eddy loss}} = \left(\frac{\text{r. m. s. voltage}}{\text{flux voltmeter reading}}\right)^2$$

A correction, therefore, has to be applied for the changed eddy loss. The method used in the tests described below was as follows. If, in a normal sample at sine-wave voltage, the percentage values of the eddy and hysteresis losses are known over the desired range of densities, then, if the eddy-current loss is left unchanged and the hysteresis loss altered and if for the test purpose the voltage is set by the flux voltmeter, it follows that the

True sine-wave core loss

$$= \frac{\text{Observed total loss} \times 100}{\text{Per cent hysteresis} + k \times \text{per cent eddy loss}}$$

where k is the square of the ratio of the a-c. voltmeter reading to the flux voltmeter reading. The relative values of the eddy and hysteresis losses in the iron sheets may be obtained from the Epstein test[2].

2. Since the preparation of this paper, an excellent method used by the Bureau of Standards has come to the attention of the writer in which no assumption whatever is made about the percentage values of the eddy and hysteresis losses but two measurements are made at different wave shapes to obtain the separation of the actual eddy and hysteresis losses. The method, of course, involves the use of either the flux voltmeter or its equivalent in some form. The method is quite simple.

The core loss test is made at two different wave-shapes, setting the voltage by the flux voltmeter. Assume that W_1 and W_2 are the observed total losses, and E_1 and E_2 the corresponding observed effective a-c. voltages. Then the true total core loss W_s for the rated sine wave voltage E_s indicated on the Flux Voltmeter is

$$W_s = \frac{W_1(E_s^2 - E_2^2) + W_2(E_1^2 - E_s^2)}{E_1^2 - E_2^2}$$

This is derived from the following basic equations:—

$$W_1 = H + W_0 E_1^2$$
$$W_2 = H + W_0 E_2^2$$

in which H is the hysterisis loss and is the same at both wave-shapes for the same flux voltmeter voltage; while W_0 is the eddy-current loss for unit effective voltage, and when multiplied by the square of the actual effective voltage gives the total eddy-current loss for that test.

The fact that the percentage eddy loss varied at different densities is to be taken into consideration by using the characteristic curve of the material similar to the sample characteristic curve shown in Fig. 13. It is to be granted that in large built cores the ratio of eddy to hysteresis is not necessarily exactly the same as in small samples, due to increased intersheet eddies resulting from the closer contact of the sheets under pressure from highly tightened bolts. Large cores, however, have also increased hysteresis loss due to pressure of bolts and other reasons, so that in large cores the ratio of eddy to hysteresis probably does not increase as

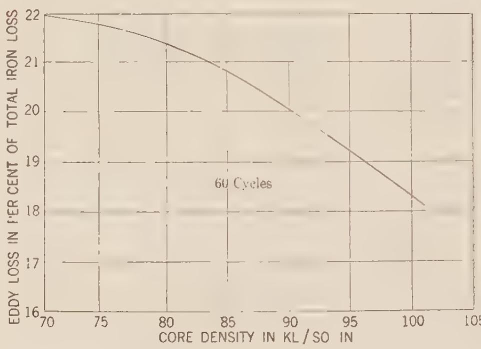

Fig. 13

much as one might expect. Furthermore, it may be shown by an example that the error that may result from this variation is not very large.

Example

Flux voltmeter setting	100 per cent rated voltage
Actual r. m. s. voltage	105 per cent rated voltage

$$k = \left(\frac{\text{r. m. s. voltage}}{\text{Flux voltmeter voltage}}\right)^2 = 1.10$$

True core loss = Observed loss

$$\left(\frac{100}{\text{Per cent hyst.} + k \text{ per cent eddy}}\right)$$

If the eddy loss is 20 per cent,

$$\text{True core loss} = \text{Observed loss} \left(\frac{100}{80 + 1.10 \times 20}\right)$$

$$= \text{Observed loss} \ \frac{100}{102}$$

The correction for error in the eddy-current loss thus amounts to two per cent. If the flux voltmeter were not used at all and no correction applied, the observed loss would be about ten per cent in error.

To show that the assumption of a considerably different percentage value of eddy loss would not affect the foregoing result appreciably, we may suppose that

the percentage is 30 instead of 20 and recalculate the true loss. We would then have

$$\text{True loss} = \text{Observed loss}\left(\frac{100}{70 + 1.10 \times 30}\right)$$

$$= \text{Observed loss}\ \frac{100}{103}$$

Comparing this with the previous result, it will be observed that a 50 per cent error in the percentage value of the assumed eddy loss has influenced the final result by only one per cent.

Test Data. In the data tabulated below, a given transformer was tested on two or more generators of widely different wave shape, thus using the degree of agreement among the results so obtained as a measure of the accuracy of the instrument in this application. An attempt was made, of course, to make one of the wave shapes in each instance as near sine wave as possible and the other, or others, as distorted as possible. Oscillograms of wave shape are shown for each instance. Furthermore, to give to the reader an idea as to how much the wave-shape error would have amounted to if no attempt at correction for wave shape were made, the losses observed when the voltage was set by an a-c., r. m. s. voltmeter are also given for each instance.

Since in these tests the comparative values of the losses rather than their absolute values are of interest, the loss data, to facilitate comparison, have all been reduced to percentage values calling one of the readings as 100 per cent.

TABLE I

Item	Trans. Kv-a. Rating	Generator Kv-a. Rating	Per cent Load on Generator	Core Loss with Flux-volt	Core Loss without Flux-volt	Oscillo-gram Fig.
				Per Cent	Per Cent	
No. 1	1,500	500	20	100	81.6	6
	"	1,500	7	100	94	7
No. 2	1,667	500	30	100	88.5	8
	"	3,000	5	100	94.2	9
No. 3	8,000	500	55	100	87.8	10
	"	1,500	18	100.5	92.2	11
	"	12,000	2.2	99.5	98.8	12
No. 4	10,000	500	50	100.3	83	—
	"	3,000	9	100	93	—
	"	12,000	2	100	101.5	—
No. 5	28,866	1,500	45	100	82	
	"	24,000	3	100	90.8	

These data would seem to indicate excellent commercial accuracy for the flux voltmeter, inasmuch as practically the same result is obtained no matter how distorted or how pure the waveshape is. The distortion of the wave in some instances was so great (see item No. 1) that more than 18 per cent error would have existed in the core-loss measurement if the voltage had been set by an r. m. s., a-c. voltmeter.

Comparison With Other Methods

Two very similar methods have in the past been used for the purpose of reducing core-loss measurements to a sine-wave basis. It may be of interest, therefore, to present data as to how the accuracy of the flux-voltmeter method compares with theirs.

In the two older methods, use is made of a little "Standard" transformer the core loss of which has been calibrated on pure sine-wave voltage. In both methods, this "standard" transformer is excited, through potential transformers when necessary, in parallel with the power transformer under test. In one of the schemes, the voltage of the circuit is adjusted to a value such as to make the core loss of the "standard" the value corresponding to the desired sine-wave voltage. In the other scheme, the desired voltage is set by an r. m. s. voltmeter and the actual losses in both the power transformer and the little "standard" are observed. The factor which would convert the observed core loss of the little standard into its sine-wave value (known from its calibration curve) is used to convert the observed loss of the power transformer to sine-wave basis.

Tests indicated in Table I for the flux voltmeter were repeated, making corrections by these two schemes. The items in the following tabulation refer to the same apparatus and conditions as the corresponding items in Table I.

TABLE II

	Core Loss by		
	Flux-Voltmeter	Scheme No. 1	Scheme No. 2
	Per Cent	Per Cent	Per Cent
Item No. 1	100	90	91.7
	100	95	95.4
Item No. 2	100	93.3	94.2
	100	95.3	98.2
Item No. 3	100	95.2	98.8
	100.5	97.6	99.2
	99.5	99.2	102.
Item No. 4	100.3	95	96
	100	97	103.5
	100	109	111
Item No. 5	100	90.2	93.6
	100	97.4	97.4

It is interesting to note that (1) core-loss measurements made by the older schemes are influenced a great deal by differences in wave shape and that with badly distorted waves they would be very unreliable, and (2) that in eleven cases out of twelve, the losses obtained by the older methods were considerably less than those obtained by the flux voltmeter (and the one instance, in which they were more) might be somewhat doubted.

Outfits of this type have no doubt served an excellent purpose in the past, and even now, when the wave distortion is not large, they may give results which are entirely satisfactory. On the other hand, however, it appears that conditions have so changed in recent years that the average accuracy which was obtained

by the aid of such outfits five or ten years ago is not readily obtained under present conditions. The reasons for this may be seen as follows:

1. These older schemes do not attempt to maintain a known flux density in the core, but aim at drawing inferences from the losses of a small unit to the losses of the main transformer. If the two transformers were operated at the same density, this might be possible, assuming that other conditions are favorable. It is not practicable, however, to duplicate the density of the main transformer in the auxiliary "standard" core, and therefore the greater the difference in density the less reliable is the result. Scheme No. 2 described above utilizes an extra theoretical correction based on the difference in the density of the two transformers and it will be observed that it gives, in general, more correct results than scheme No. 1. Still, it is not by any means as consistent and accurate as the flux voltmeter.

2. Transformer sheet steel is constantly being improved, so that hysteresis characteristics and the eddy-current ratio are modified as time goes on, and the assumed "standard" core, even when operated at the same density as the transformer under test, ceases to be representative in a short period of progress. Even at a given time, a great variety of sheet steels are used, and it would be impossible for a given "standard" core to duplicate the characteristics of them all.

3. Although the kv-a. capacity of transformers built in recent years has steadily increased, the kv-a. capacity of generating units used for testing the core-loss of the transformers has not proportionately increased, and as a result, the core-loss load on generators in testing departments is a much larger percentage of their capacity and as a consequence the wave distortion is on the average much larger than formerly. It may be noted that generator voltage wave distortion due to transformer exciting current load is far more than that due to other loads, on account of the fact that the former draws a badly distorted current. Even in a carefully designed generator, the harmonics of the transformer exciting current will produce a large distorted regulation through the usually high synchronous impedance of the generator.

Application of Flux Voltmeter to Alternating Flux Networks

In a magnetic network, the flux density in different branches may be badly distorted, even with sine wave line voltage and sine-wave total flux. In such cases, observing the r. m. s. voltages in exploring coils on different branches would not indicate the true flux densities in the respective branches, whereas voltage observations made by the flux voltmeter would definitely and correctly indicate the corresponding densities regardless of the shapes of the waves, provided, of course, that the voltage wave does not cross the zero more than twice per cycle. This application is too simple to require any further comments.

Conclusions

1. A voltmeter, suggestively called "flux voltmeter," is described for a-c. circuits, the indications of which are proportional to the arithmetic average value of the voltage wave and hence proportional to the maximum flux density, if the voltage is the reactive drop corresponding to the flux.

2. The primary application of the instrument is to the reduction of the core-loss measurements of transformers to sine-wave basis. The method is to set the desired value of the voltage by means of this instrument, in which case the maximum flux density in the core corresponds to the desired sine-wave voltage, even though the impressed voltage is badly distorted. Methods are indicated for taking into consideration the error in the eddy-current loss. Accuracy of the meter in this application is believed to be within one-half of one per cent.

3. In comparison with other and older schemes for the reduction of core loss to sine-wave basis, it is noted that the flux voltmeter has the following advantages:

   a. Its results are unaffected by the rated flux density of the transformer core.

   b. It is unaffected by the quality of the core material used.

   c. It is applicable to all commercial frequencies.

   d. In general, core losses obtained by other schemes are smaller than those obtained with the aid of the flux voltmeter.

   e. The flux voltmeter puts practically no load on the instrument transformers.

4. The flux voltmeter may also be used for exploring alternating flux networks.

5. The only limitation of the flux voltmeter seems to be in those instances in which the voltage wave crosses the zero line more than twice per cycle. Such distortions of voltage waves, however, are so rare commercially that it is difficult to conceive of encountering them in practical core-loss tests.

The author is indebted to Mr. C. A. Read for the taking and analysis of the oscillograms; to Messrs. M. G. Newman and A. Boyajian for advice in the progress of the investigation; and to Mr. L. de Nagy for assistance in making the tests.

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Excellent Seminars for Practising Engineers:

A Challenge to Engineering Teachers

BY EDWARD BENNETT[1]

Fellow, A. I. E. E.

STATED in broad and comprehensive terms, the *primary responsibility* of the engineering colleges is for the development of four groups of men; for engineering work namely,

a. Undergraduate students
b. Graduate students
c. Practising engineers
d. Engineering teachers.

The responsibility of the colleges of engineering for the first two groups is evident and is not discussed in this paper. On the other hand, the possibilities of educational activities with the third group are just beginning to appear on the educational horizon, and the question naturally arises as to the grounds for listing such activities as a responsibility of the colleges.

Two considerations seem to warrant our regarding educational activities with practising engineers as responsibilities, or at least as promising fields of service for the colleges of engineering.

First. An appreciable percentage of practising engineers and of engineering teachers contend that an adequate foundation for an engineering career cannot be obtained in the four-year course. They advocate the plan of keeping the engineering students within the college walls for an add tional year or two. If this contention is well founded, but if, for one reason or another, it is not deemed best to require engineering students to remain on the campus for a fifth year, it seems logical to consider the extent to which it may be feasible to carry the college to the young engineer in practise.

Second. It is a commonplace that most engineers (and this applies equally to a'l of the professions including the teaching) are unable to keep abreast of the rapid scientific developments in their field, and as a result are not in a pos'tion to do clean cut effective work. There would seem to be a distinct opportunity for the colleges to be of service to engineers whose training along scientific lines may have been quite adequate at the time they entered practise but who have come to feel the need of a fundamental re-examination of certain fields.

In view of these considerations and others to be presented later, it would seem that the engineering colleges should, by trial, determine the feasibility and desirability of conducting in nearby engineering centers *seminars* or *conferences* of one or more of the following types for practising engineers.

Type A. Advanced studies of the kind given in residence in postgraduate work; studies in mathematics, physics, engineering subjects, etc.

Type B. Seminars dealing with recent developments, designed to enable he older graduates to keep abreast of the scientific advances.

Type C. Seminars for the discussion, in the light of fundamental theory, of

a. Allied or common research problems
b. Allied or common design problems
c. Allied or common operating or manufacturing problems.

A brief sketch of two seminars for practising engineers sponsored by the University of Wisconsin may be of interest.

Two years ago a group of technical graduates of ten or more years' experience, and all in responsible positions in the metallurgical industries, requested the opportunity to work for an advanced degree and to carry on this work in Milwaukee, 85 miles east of Madison, the seat of the University. Since an experimental research in some technical subject would be a necessary part of the proposed graduate work, the proposal was welcomed because it held promise of opening the way to a very desirable type of cooperative research between the engineering industries and the college. I refer to the type of research in which problems are not brought to the college laboratory to be solved, but, in which the facilities and views of the college, are carried to the industrial laboratory or the engineering office, and in which the primary function of the college in research—namely, the training of men in engineering research—is emphasized and is given wider scope. The positions held by the eight men in this group are as follows:

Works Manager of the Milwaukee Steel Foundry Company

Vice-president of the Badger Malleable Company

Works manager of the Globe Electric Company

General superintendent of the Federal Malleable Company

Metallurgist of the Federal Malleable Company

Metallurgist of the Glancy Malleable Corporation

Metallurgist of the Vilter Manufacturing Company

The *significant* thing about the list is that these men are in competing industries and are cooperating in a highly effective manner in the solution of their common problems.

During the past two school years this group has met in Milwaukee each Friday evening for a conference extending from 7:30 to 10:30, or later, with Professor R. S. McCaffery or other members of the Mining

1. Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.

Presented at the A. I. E. E. Regional Meeting of District No. 5, Madison, Wis., May 6-7, 1926.

or Metallurgical Department.[2] On Saturday, the professor visits one or possibly two of the members of the seminar at his plant or laboratory and discusses the research project which is under way. The research projects, which were selected by the men themselves, are as follows: A study of the reactions which take place in a basic steel furnace; an electrical method of rapidly determining the quality of the molten metal in malleable air-furnaces; the determination and comparison of the heat balances of hand-fired, oil-fired and pulverized-coal-fired malleable furnaces; the effect of silicon and manganese on the properties of malleable iron; and the study of the reactions of combustion in a malleable furnace for the purpose of obtaining greater accuracy of control of the finished product.

In the conduct of a seminar for the discussion, in a fundamental way, of allied questions, the first and most difficult problem which presents itself is that of getting the members of the group to talk the same technical language. This requires a review of the experiments, concepts, postulates, definitions, sequences and principles which underlie the branch of science with which the group is concerned. Accordingly, the Friday evening conferences during the first five months were devoted mainly to a review of the fundamentals of physical chemistry applied to metallurgy. This involved a study of equilibriums in chemical and metallurgical reactions and of equilibrium diagrams, the application of the phase rule, mass law, atomic structure and the velocity of reactions.

The impression made by this work is indicated first, by the fact that some of the concerns listed above have established fellowships at the university in order that the holder of the fellowship might collaborate with the member of the seminar by carrying on supplementary researches at the university, and second, by the fact that some 26 grey iron foundaries operating in the Fox River Valley have formed a local association to carry on and finance cooperative research at their own plants and in Madison; a similar group of about 20 grey iron foundries in Milwaukee is organizing to carry out a program of the same kind.

The second seminar was organized at the solicitation of electrical engineers in Milwaukee. The men in this group, which started with 18 men and ended with 13, are electrical engineering graduates with from two to six years of experience. During the past year this group met in Milwaukee each Thursday evening with a professor from the university for a seminar of the A type,—a seminar for the discussion of *transient phenomena and waves in electric circuits.* This course was largely a mathematical development of circuit theory, with, of course, constant illustrations of the application of the theory to transformers, generators and power and communication systems. As a result of the experience of the men with this seminar, courses of a similar nature have been solicited and will be given during the coming year. At least one industrial organization has under consideration plans for meeting all or part of the tuition expense of its employees who successfully complete courses of this kind.

2. For a more detailed statement of this work, see the paper by Professor R. S. McCaffery entitled "Research Cooperation between University and Industry," Canadian Inst. of Min. & Met., Vol. XXIX, 1926.

The Significance of the Seminars to Industry

It may be well to list the significant possibilities to industry of seminars conducted by the engineering colleges for men engaged in engineering practise. They are:

Such seminars, if available, will enable some graduates of four-year engineering courses to obtain a more thorough scientific training for engineering work.

Seminars of the B type might be used to serve as the line of communication between the advance scientific workers and the main body of engineers, or to enable engineers who, in the press of work, have lost touch with certain allied fields, to "come back" in these fields.

During the apprenticeship period of the first few years after graduation, many engineering graduates slip in their grasp of mathematical methods and analysis. A course of the A type, if pursued during this period, should be of value in more firmly fixing these methods and in warding off the mental slump which frequently occurs during a depressing apprenticeship period.

That both industry and engineering education have much to gain by closer cooperation in engineering work, particularly of the research type, needs no argument. The kind of cooperation which has received more attention in the past is that in which certain research problems have been taken to the college laboratory for solution. By seminars of the C type, the views and the methods of the college are carried to the industrial laboratory, and the primary function of the college in research—namely, the training of its own staff and of its students in research—is made more apparent and is given wider scope. More research for engineering teachers both in the college and in industry is badly needed.

Engineering seminars sponsored by associations formed by the smaller industrial enterprises for the fundamental examination of their common technical problems may be a means by which the smaller enterprises with their desirable social characteristics may retain a place in the sun by the side of the modern corporation.

One of the barriers in the way of more effective cooperation between the industries and the state colleges results from a difference in the social philosophies in the two fields of action, namely, in the industrial field and in the professional field in general, or the teaching field in particular. In the educational and scientific field, the rewards and increased opportunities come from the sharing and free disclosure of all

achievements which result in the advancement of knowledge. In the industrial field, the careful guarding of trade secrets is still regarded in many industries as highly essential, and the obtaining of exclusive rights through patent control is frequently the main consideration which leads to the support of research work. These conflicting demands—for the unreserved disclosure and for the exclusive use of knowledge—are the greatest barrier in the development of cooperative relations in those fields in which important improvements and inventions are likely to be made.

The most promising sphere for the organization of seminars for the consideration of allied or common engineering problems is with associations of manufactures or of public utilities. In this case it would seem quite possible to formulate a policy with reference to the granting of preferential but not exclusive patent rights which would harmonize the views and rights of all parties in the enterprise. The essential features of such a policy are outlined in Sec. VIII and IX of Circular No. 9 of the Engineering Experiment Station of the University of Illinois, entitled "The Functions of the Engineering Experiment Station of the University of Illinois," by C. R. Richards.

Not the least among the possibilities for good of these seminars is the possibility that the advantages of cooperation may be shown to be so great that it may become obvious that the thing to do is to modify those features of the patent law which make the existing law a barrier to cooperation.

The type of seminar which holds the greatest promise of achievement is a seminar of experienced engineers from the same or allied fields who have come together to conduct a critical analysis of certain cases or certain lines of engineering practise. It may seem like presumption to suppose that men from the colleges can be of much service to such a group. The presumption is tempered somewhat by the consideration that the introduction of a foreign body into saturated solutions frequently initiates crystallization. In a group of experienced engineers, the man from the college may at least play a role not unlike that of the foreign body in the chemical solution. The achievements should come mainly from the contributions of the practitioners to the conference. Judgment should not be passed as to the relative contributions to be expected, however, until we have considered the significance of these seminars to the engineering teachers.

Significance of the Seminars to Engineering Education

The fourth responsibility of the engineering college is for the development of engineering teachers. One of the strongest arguments for sponsoring seminars for practising engineers is the part which these seminars will play in the development of engineering teachers.

The seminars will compel and will reward a broader and a more thorough training than is common in the teaching ranks today.

They will afford greater opportunities to determine the adequacy, the relative importance, and the real significance of the principles and the methods taught to undergraduates.

They will make teaching attractive to a wider range of engineers by making it possible for men in teaching to have closer contact with engineering practise.

They will help to supply one of the greatest needs of the engineering colleges of the country; namely, the atmosphere, the spirit and the prestige which will accompany more examples of engineering work in progress or carried to a successful conclusion in the colleges or by the engineering teachers.

The opportunity to develop these seminars comes to the teaching profession as a challenge; a challenge because the task is no light one but one beset with difficulties and even with an element of danger to undergraduate instruction; but above all, a challenge because the acceptance of the opportunity means the acceptance of a goad and the acquirement of an incentive which will bring the work of the engineer and of the engineering teacher to a higher plane.

WELDING LARGE METAL STRUCTURES

The American Bureau of Welding, 29 West Thirty-ninth Street, New York, N. Y., is planning an extensive investigation of welded steel structures. James H. Edwards, assistant chief engineer of the American Bridge Co., 71 Broadway, New York, N. Y., one of the directors of the American Bureau of Welding, is interested in this method of fabrication, which may have many advantages over riveting.

Electric arc welding was used by Mr. Edwards' company to fabricate some steel plates in order to determine the difficulties which might arise in using this process. The result was a plate girder 15 feet long, having a web plate one-half inch thick and 24 inches deep. The flanges were 12 inches wide, one 1¾ and the other 1⅞ inches thick. A cover plate 9½ inches wide and nearly as thick as the flange was used on the top and the bottom flanges. Nine stiffeners on each side were welded to both flanges and the web.

To determine the strength of this structure, particularly whether or not the welds were satisfactory, it was tested by the Bureau of Standards in cooperation with the American Bridge Co. The Olsen hydraulic machine, having a capacity of 10,000,000 pounds, was used, loading the girder at the middle of a 13½-foot span.

It was gratifying to find that the maximum load was somewhat greater than this estimate, and that the welds connecting the web to the top flange failed at the ends only after the web was buckled and the girder had deflected several inches.

The investigation will enable an engineer to design safe welded structures. It is probable that a saving in the cost of steel structures will result.

Discussion at Midwinter Convention

THE CALCULATION OF MAGNETIC ATTRACTION[1]

(LEHMANN)

NEW YORK, N. Y., FEBRUARY 11, 1926

C. O. Mailloux: This is another of the papers of the kind which, like one by Mr. Fortescue[2] published some years ago and one by Mr. Rice[3], written more recently, serves to advance our knowledge of ways and means of attacking problems that have baffled all others before these authors, and at the same time gives us very interesting evidence of the fact that the methods of mathematical treatment of previous generations—say of the days of Maxwell, Kelvin, Mascart, Helmholtz, etc.—are still capable of giving magnificent results. Mr. Fortescue, in an epoch-making paper, showed the valuable use that can be made of the principles of the *potential energy function* and of their application to the discussion of equipotential surfaces, etc., as a means of mapping out the field of electric force around insulators that are subjected to high electrostatic stresses. Those who may have had doubts at that time in regard to the utility of the study of the potential function as a preparation for the analysis of phenomena in fields of force, and were disposed to look more sympathetically upon the more "modern" methods devised or elaborated by Bjerknes, Lorenz, and others, found that their fears in regard to the "staleness" of the older methods were not wholly well founded. What Mr. Fortescue did was, in a sense, an extension of Maxwell's work, and his diagrams of lines of electric force in electrostatic fields show at least a family resemblance to some given in Maxwell's treatise. Mr. Rice's able paper furnished further valuable evidence of the great usefulness of this method of attack on seemingly difficult problems of like character.

In the present paper, we have the very interesting case in which the theory and the principles of the potential function enable the author to perform an entirely new *tour de force* that would have done credit to Maxwell himself, showing such a simple and practical way of "surveying" and *appraising* the magnetic force in an air-gap that we wonder how such a clever expedient has remained so long undiscovered. Every student of the theory of the potential function knows that the concept of the "tube" of magnetic force, even though it may be after all only a figment of the scientific imagination, does account, in a very simple way, for differences of magnetic density and distribution that are often impossible to describe by any other method, notably by the measurement or expression of variations in magnetic density in different parts of the magnetic field. It was an inspired idea of the author to decompose the magnetic field in the air-gap into *elemental tubes of magnetic force*, with boundaries (or envelopes) enclosing spaces in which the magnetic flux is constant. This amounts virtually to the same thing as finding paths across the air-gap where the magnetic density may be treated as if it were constant. In this way the author found a means of getting across the air-gap without having to stop midway to rearrange and readjust the magnetic density; and with the aid of the principle of "solenoidal distribution" and of equipotential surfaces, all of which is a part of the theory of the potential function, he had the absolute certainty of being able to get across safely before he started. The only problem that remained to be solved was that of making "landings" at both ends of the path followed in crossing the air-gap through a tube of magnetic force when that path is not exactly straight across, *i. e.*, when the tube of magnetic force is not "normal" to the surface of the poles or other ferromagnetic portions of the magnetic circuit on the two sides of the air-gap. The author solved that problem in the well-known, simple way, familiar to mathematicians, of replacing any contour line by an equivalent broken line, on the principle that a circle may be regarded as a polygon of an infinite number of sides. Now, the fundamental fact that makes this method rigorous as well as interesting and effective is the well-known principle that whenever a potential energy function *exists*, as is the case in an air-gap, the *initial* and the *final* stages of the potential developed (which in this instance is magnetic potential; that is to say, the conditions determining the *strength* of the physical *bond* between the two edges of the air-gap) are really independent of the locus of the path through which the tube of force is "laid." Indeed this far-reaching generalization, a great achievement and precious inheritance from the mathematical physics of previous generations, was the key that unlocked the secret of the wide power and range of the method and that inspired confidence in it by showing how far it can be relied upon.

The paper deserves to be regarded as a pathfinder, pointing the way to new and really wonderful applications of old but still "up-to-date" and most effectual methods of attacks on difficult problems. It is seen that the figments of the scientific imagination, to which I have just referred, can play a most important role and can lead to highly useful concrete results as they did in Mr. Fortescue's paper. As in that case (aside from the useful practical applications) the result is a contribution to general theory and will add value in a permanent way to the TRANSACTIONS of the Institute.

The paper may not prove as easy of perusal and comprehension as might be, because some of the ideas in it are presented somewhat tersely and are not, therefore, placed within as easy reach of the ordinary reader as might have been, perhaps, had the author realized the desirability of so doing. The mathematics are simple enough; in fact, they are elementary to those who have studied the theory of the potential energy function and mathematical physics to even a slight extent, although they may seem abstruse, imposing, and forbidding to those who have not done so. The paper really deserves to be made accessible to a very large constituency. This could have been done easily by taking a little more space for the presentation of the mathematics in slightly more "dilute" form. The objection most often made to papers of this type is, indeed, that their authors do not sufficiently recognize the importance of making them entirely clear to those who do not know or remember as much as they do themselves about the "short cuts" in mathematical transformations and demonstrations. A few notes given in an appendix, clarifying the more abstruse portions, would help greatly to remove the impression that the paper is merely a "high-brow" product which will, or can, interest only mathematical students and experts. In this respect, however, the paper will be found to be not nearly so formidable as it may look. Moreover, those who are interested in this general subject will find such additional information and elucidation in other articles by Dr. Lehmann which have appeared in the *Revue Générale de l'Electricité*; notably in the article published in the numbers of July 12 and 19, 1924. This was written at about the same time as the present paper and covers substantially the same ground, but does it in a more detailed manner, and also throws full light upon the theoretical considerations which the author kept in mind and which underlie the methods described in the paper.

J. Slepian: It is usual to derive the forces acting on material bodies in a magnetic field by starting with the principle of conservation of energy, calculating the electrical energy input and the increase in magnetic energy, and assuming that the difference in these quantities gives the work done by magnetic forces on bodies which are displaced. This is the procedure followed by Doherty and Park in their paper.[4] Mr. Lehmann, however,

1. A. I. E. E. JOURNAL, February, 1926, p. 167.
2. TRANSACTIONS A. I. E. E., 1913, p. 907.
3. TRANSACTIONS A. I. E. E., 1917, p. 905.
4. *Mechanical Force between Electric Circuits*, by R. E. Doherty and R. H. Park, A. I. E. E. JOURNAL, March, 1926, page 231.

starts with Maxwell's expression for the stresses in a medium in which a magnetic field exists.

In the time of Maxwell, the great program of physics was to explain all phenomena mechanically. Therefore it was very natural to try to explain the transmission of force over distance through the mediary of a magnetic field by a mechanism similar to that by which force is transmitted mechanically through material bodies, namely by a system of mechanical stresses. Maxwell was led to believe that the following system of stresses would account for the mechanical forces in a magnetic field: a tension equal to $H^2/8\pi$ per sq. cm. across any surface perpendicular to the lines of magnetic force, and a pressure equal to $H^2/8\pi$ across any surface parallel to the lines of magnetic force.

In applying these stresses to determining the forces on material bodies, however, a difficulty arises, for these stresses are supposed to exist in empty space or in the ether as well as in material bodies. And since the ether pervades all material bodies, we cannot tell how much of the stress at any point acts on a material body there, and how much is limited to the ether. Maxwell resolved this difficulty to some extent by showing for a stationary magnetic field that although these stresses do not give the actual ponderomotive force at each and every point of a material body, when integrated over a closed surface, they do give correctly the total ponderomotive force on all the material bodies enclosed in that surface.

Herein lies one of the difficulties which I have found in trying to follow Mr. Lehmann, for apparently he integrates the stresses over a surface which is not closed. Such a procedure if carried out, for example, over a portion of the surface of a wooden body would give a resultant force, and yet we feel quite sure that no such mechanical force exists on any portion of such a body. If the integration is carried out over the whole surface of the body, the correct zero resultant is obtained, but not if the integration is limited to a part of the surface.

It is easy to see that if a body has infinite permeability, then integration over any portion of its surface will give correctly the mechanical force on that portion, and it so happens that the example which Mr. Lehmann has worked out is for a body with infinite permeability. But if the method is applicable to the case of finite permeability, it seems to me that some further justification is necessary. I would be very happy if Mr. Lehmann could clear up this point for me.

The formula which Mr. Lehmann has obtained is similar to that obtained by Doherty and Park by considering displacement of a magnetic body under constant flux, and I presume is intended to apply also for the case of saturation. However, Mr. Lehmann does not limit himself, as do Doherty and Park, to special magnetic circuits where the flux density is constant in the air gap during the displacement, but suggests that the result is general. This is a question of very great importance and I therefore considered it worth while to try to derive this result from the principle of conservation of energy. In so doing I ran upon a difficulty which Mr. Lehmann hints at in his paper but which I have not been able to surmount. Perhaps Mr. Lehmann can show how to take care of it.

I used the following artifice: In the magnetic system under consideration, assume that all currents which are flowing are in resistanceless circuits so that no impressed voltages are required. Now assume that with the bodies in the position for which the force is to be calculated, all bodies which are subject to magnetic saturation are made infinitely conducting. No change in the magnetic force results from these hypotheses. Now let one of the saturating bodies be displaced a small amount, Δx. Then currents are induced in the various circuits and conducting bodies, the magnetic field changes, and work is received by the moving body. Now, since the electromotive forces are zero, there is no input of electrical energy. Hence the work received by the moving body must be equal to the decrease of magnetic energy. Since the saturating bodies are by hypothesis infinitely conducting, there will be no change in the magnetic field within them at any point, so that the magnetic energy in their interior remains constant. Hence the whole change in magnetic energy is external to the saturating bodies. This change in the external magnetic energy may be resolved into two parts. First we may consider the change which would take place if the energy density at every point remained constant, so that the motion of the saturating body merely changed the boundaries of the external field. This change may be determined by multiplying the energy density at each point of the surface of the body by the normal component of the displacement of the surface and integrating over the whole surface. This change in magnetic energy considered by itself leads directly to Lehmann's formula. However, there is the second part of the change in magnetic energy which must be considered; namely, that due to the change in energy density at the various points of the field. If ΔW is the change in magnetic energy density at any point of the field, resulting from the displacement of the saturating body, then the volume integral,

$$\int\int\int \Delta W \, dx \, dy \, dz$$

taken over the whole external field gives the other part of the change in magnetic energy.

If Mr. Lehmann's result is correct, this integral must be equal to zero. However, I have not been able to establish the fact that this is necessarily the case and would like to ask Mr. Lehmann if he can suggest how this is to be done.

R. H. Park: Two methods of calculating the mechanical forces due to magnetic attractions have been presented at the 1926 Midwinter Convention; namely, a method of calculation based on analysis of flux through circuits, and a method based on the analysis of stresses acting at each point of a closed surface bounding the volume on which the force is to be calculated. Both methods have special fields of application in which they are of particular value. In the formula

$$F_l = \frac{\phi^2}{8\pi} \quad \frac{\delta R_o}{\delta l}$$

of the paper by Dr. Lehmann, he has given a useful simplification of the known methods of calculating force on the basis of stress acting on bounding surfaces. For this particular result and also for his introduction of the general method of calculating force from stresses on bounding surfaces to problems of practical character, Dr. Lehmann deserves much credit. Without wishing to detract in any way from the practical value of Dr. Lehmann's paper, I should like to mention a few considerations which may deserve attention.

In particular, the application of formula (1) of the paper to problems in which saturation exists both within and without the volume in which the force is to be calculated may be open to question. In his "Electrical Papers," Volume I, pages 542 to 553, and Volume II, pages 543 to 574, Oliver Heaviside shows definitely that formula (1) applies in the case of saturation when there is no saturation outside the region on which the force is to be calculated. He also gives a formula which applies in the more general case and in the interior of saturated regions. This result would indicate that formula (1) of the paper was correct in application in the case when there is iron both within and without the region on which the force is to be calculated, if the intersurface does not pass through saturated material. The arguments employed, however, in establishing these results are not entirely clear since no explanation is given that the assumptions on which the proof is based are in accord with experimental facts.

In regard to Dr. Lehmann's definition of his reluctance R_0, it may be pointed out that the determination of this reluctance requires a previous knowledge of the distribution of the field in the region under consideration. It therefore depends on the character of the medium at points outside of the particular

region under consideration. Also there is a difference between the term $\frac{\delta R_0}{\delta l}$ and the ordinary total derivative of $R_0 \frac{d R_0}{d l}$. The derivative $\frac{\delta R_0}{\delta l}$ corresponds to a change in δl with the flux density and direction of the field fixed at the bounding surfaces.

C. O. Mailloux: With reference to the remark made by two of the discussers that the method is of direct application to questions where the permeability is independent of the field, that statement is brought out in the paper itself. The author concedes that point and there is no question about it. At the end he does refer to the fact that the formula can be completed by a saturation factor, but there is no detailed reference given to that, so we may assume that he didn't feel sufficient confidence in that new development to introduce it into the paper.

The inquiries made by one of the speakers are partly answered in the paper itself; notably where the author speaks of a complete integration around a circuit and counter-balancing effect produced by the integration of the second part of the circuit that is already shown diagrammatically in Fig. 10.

In regard to the detailed analysis of the formula, he preferred the purely practical method of finding what allowance, if any, could be made for the variation of magnetic field, when the length of the air-gap is increased or decreased, by calculating two cases where it has been done, proceeding with one from the inside and the other from the outside. He thus finds the difference between the two is within one per cent.

Now, for the cases with which he was interested in dealing, that error certainly is sufficiently small and, while the theory might be very interesting in a question of splitting hairs, it is not of immediate concern in connection with the present paper. I hope, however, that the author will be given an opportunity to explain himself to any such extent as he may deem necessary.

In the paper he does not mention the potential function, but anybody at all familiar with the subject knows that it is based upon that. One of the characteristics of potential function is that it goes into no speculation as to action at a distance. That may be the difficulty encountered by the gentleman. It is independent of all speculations as to the intervening medium or the actions at a distance. Had the author wished to go into it, he would have to begin by discussing the physics and mathematics of a tube of force, itself. He has assumed that as implicitly as one would assume the multiplication table in mathematics. Hence, if that is accepted as a fact and the explanation is sought for in some other books on mathematics, it seems to me a great many of the difficulties will disappear.

Th. Lehmann: I am indebted to Mr. R. H. Park and to Mr. J. Slepian for giving me, by their remarks, an opportunity to define further the scope of my paper. I also thank Dr. Mailloux for already having replied in part to their discussions.

My A. I. E. E. paper is a condensed summary of articles which have already appeared in the *Revue Générale de l'Electricité*, (Paris), July 12th and 19th, 1924, in which I made explanation (especially in paragraph VIII) of the fictitious character of Maxwell's stresses and pressures. In writing the A. I. E. E. paper it appeared to be desirable to leave out that paragraph and certain others to avoid lengthening it too much. In saying in the introduction to my paper, however, that I was taking into consideration only the resultant magnetic effort produced in a ferromagnetic body entirely surrounded by air, it seemed to me that there could be no doubt that the formulas (1) and (4) should be integrated along the *whole* of surface S in the body, especially since the letter S was added at the bottom of the integral sign to show that a *surface-integral* was intended.

Maxwell himself observed that the vectorial function, $P/8\pi$, which appears in the integral expression, is of fictitious character, inasmuch as it represents magnetic effort per unit of surface. The fact of having shown how this function may be evaluated and used in the determination of the true resultant does not at all imply that a real entity is attributed to the elemental effort per unit of surface, $P/8\pi$.

This point now having been made clear, I wish to assert that, for any closed surface of integration, the formula

$$F = \int_S B_{2\alpha}{}^2 \, d S, \tag{4}$$

is equivalent to formula (1), the range of validity of which seems to have been determined previously by Oliver Heaviside. In any case, formula (4) gives exactly the *resultant* magnetic effort exerted upon a ferromagnetic body, C, having a surface, S, entirely surrounded by air, whether the permeability of the body be variable or not and even when the body, C, has hysteresis[5]. In the external medium, (the surrounding air), there may be other saturated ferromagnetic bodies and also some currents, provided the whole of the surface, S, of the body, C, be separated from the other ferromagnetic bodies by an air-zone.

Here I shall go no further than to state that I have given elsewhere (in the *Revue Générale de l'Electricité*, 1925, Vol. XVII, p. 167) the demonstration of the validity of formula (4) for a body, C, that is saturated but free from hysteresis, this being done by means of a schedule of the virtual potential energy involved, obtained by applying the theorem of W. Thomson. Another demonstration which does not use this theorem but which also includes the case where the body C is not free from hysteresis will appear shortly in the *Revue Générale de l'Electricité* (in September or October, 1926).

The same conditions, as regards validity hold also in the case of the formula

$$F_l = \frac{\phi_0{}^2}{8\pi} \frac{\delta_{R0}}{\delta l} \tag{7}$$

If, for the value of the flux, ϕ_0, we take the circumflux[6] and, for the reluctance, R_0, the value obtained by means of the formulas (3) and (3'), with that flux, then for example formula (7) will give the *true resultant* in the direction of δl, on the armature of a dynamo. Of course, $\delta R_0/\delta l$ is the *virtual* derivative of that reluctance, and, as pointed out correctly by Mr. Park, it should not be confused with the ordinary total derivative, $d R/d l$. Naturally the formula can be applied also to each pole or to each magnetic circuit in turn. The respective magnetic efforts thus obtained should then be considered as being component portions of the total magnetic effort, and their vectorial sum will give the *true resultant effort* rigorously, whether the magnetic circuits be saturated or not.

The effort actually exerted upon a pole or upon a tooth can be determined in the manner which I have already indicated in the *Revue Générale de l'Electricité.* When there is no deformation (*i. e.* when the magnetic effort produces no change in geometrical figure) in the pole and in the tooth, the method of procedure is as given on page 101 of the issue of July 19th, 1924, in paragraphs VI and VII; and when deformation is produced, the method corresponds to the formulas (9) and (11), as given in the April 4th, 1925 issue. If Mr. Slepian will kindly refer to these earlier papers, I dare say that he will recognize the fact that the fictitious character of Maxwell's stresses and pressures had not escaped me in the least. But all this was quite outside the scope

5. It should be stated that A. Liénard has already pointed out (in the *Revue Generale de l'Electricite* of October 20th 1923, p. 563) that the formula (1), when integrated on the *air* side along the surface of a ferromagnetic body with hysteresis gives exactly the resultant magnetic effort. Moreover, A. Guilbert has given a very satisfactory experimental confirmation of formula (7) in his paper (Paris, 1926) which was published as a supplement to the Bulletin of the Société Francaise des Electriciens for January 1926.

6. That is to say, the absolute sum of the fluxes per pole which are common to all the poles; this, in the case of an armature which is not excentric in the magnetic field, is the same as the product of the number of poles and the flux per pole.

of my A. I. E. E. paper; in that I intended to take into consideration only the effort exerted upon a ferromagnetic body that is entirely surrounded by air.

The evaluation of the virtual derivative of the reluctance of the air, $\delta R_0/\delta l$, should be made by reference to Fig. 4 to 7A whenever the boundary air-surfaces may be considered equipotential, of which condition the reader is duly warned at the beginning of paragraph V (by the condition $\mu = \infty$ in the iron). In the case of superficial saturations of the pole-pieces of the armature, up to $B = 18{,}000$ c. g. s. (or $\mu > 100$), the departure of the lines of magnetic force passing through the air from the orthogonal direction with respect to the boundary surfaces, is still scarcely noticeable, and the methods described are still applicable with a degree of precision that is amply sufficient for practical purposes. The case given by way of example for a half-pole, should, naturally, be extended to all the poles when the magnetic field is excentric; this can be done by making δx coincide with the direction of the axis of excentricity. When the field or the armature is saturated to such a point that the lines of magnetic flux are no longer normal to the boundary surfaces, it becomes necessary to determine the segments σ' and σ'' along the whole of the air-surface for each tube of magnetic flux in accordance with the method indicated in Fig. 8; and, in that case, by following the external contour of the armature, we have

$$F_x = \frac{\phi_0^2}{8\pi} \sum \frac{1}{m^2} \left(\frac{1}{\sigma'} - \frac{1}{\sigma''} \right) \qquad (10)$$

In making the summation along a portion of the poles and of the outermost lines of force of the flux per pole that is common to both parts of the magnetic circuit, it is necessary to add, for each outer line of force, a term[7] which corresponds to

$$\frac{\phi_0^2}{8\pi m_n^2} \left(\frac{1}{\lambda_1'} + \frac{1}{\lambda_2'} \right).$$

As I pointed out in the *Revue Générale de l'Electricité* of July 19th, 1924, at the end of paragraph VIII, the elemental contributions per tube should be considered fictitious for the same reason as in the case of Maxwell's effort per unit of surface, $P/8\pi$, in formulas (1) and (4).

As to the last question asked by Mr. Slepian, it will be found to be answered fully in the article already mentioned, which is to appear soon in the *Revue Générale de l'Electricité*, and in which the magnetic attraction between bodies that are saturated and that also have hysteresis is deduced from a schedule of the actual energy involved, in a virtual displacement, without abstractions or hypotheses.

For the convenience of those who do not have ready access to the files of the *Revue Générale de l'Electricité*, a brief reference to the article published in July, 1924, may be useful.

As stated in the preface of that article, the following points are considered in it: (1) simplification of the physical formula for attraction; (2) definition of magnetic reluctance when the field is bounded by non-equipotential surfaces; (3) calculation of the virtual variation of the reluctance due to any displacement whatever of the limiting surfaces; (4) demonstration that the magnetic effort between two bodies depends only upon their common flux, ϕ, and upon the virtual gradient of its air-reluctance, R_0, and that the formula

$$8\pi F_l = \phi_2 \, \delta R_0/\delta l$$

which gives the attraction in any direction whatever, l, is as exact and general as the formulas of physics; (5) direct deduction of the attraction from the lines of flux of a magnetic figure without having to determine the components of the field; (6) evaluation of the local magnetic effort exerted upon a tooth or pole that is inserted in a groove, when the permeability is a function of the field.

The article contains nine sections, of which the last four include material that supplements the A. I. E. E. paper, which latter, as a matter of fact, was submitted to the Meetings and Papers Committee early in 1924, or before the publication of the articles in the *Revue Générale de l'Electricité*. In Sections VIII and IX, many points in regard to the validity and applicability of the formulas are made clear. Section VIII perhaps, ought to have been included in the paper. It is reproduced here (translated) with equation (13), taken from another part of the paper which could not be understood unless reproduced.

(Extract from *Revue Générale de l'Electricité*) (July 19, 1924)

"VIII. DIGRESSION. The formulas of physics for magnetic attraction are not much use in practise. Are physical hypothesis at all responsible for this? It cannot be denied that at first glance our sense of practical intuition, refined by the concept of the magnetic circuit, finds it difficult to admit the figment that excludes all disturbance in the magnetic field during a virtual displacement. But that figment, although it may lead to a state of disequilibrium, can be justified by the theorem of Thomson applied to two neighboring states of distribution, one of which corresponds to a minimum of potential energy."

It may, perhaps, be better not to look so far but simply to attribute the above reflection to the dilemmas that one meets when Maxwell's stresses are applied to surfaces which are not closed. An example will make the difficulty more clearly apparent.

Let us suppose a mass of soft iron of constant permeability, μ, and free from all internal currents. The effort exerted upon such a body in an air medium of permeability, μ_0, may be evaluated according to formula (13) in either of two ways. We have

$$\int_S P \, dS = \int_v \{ 2H \operatorname{div} B - H^2 \operatorname{grad} \mu - 2 (B, \operatorname{rot} H) \} \, dv \qquad (13)$$

The term on the left-hand side is a surface-integral which is equal to (3), or

$$F = \frac{1}{8\pi} \int_S \{ 2H (B, N) - N (H, B) \} \, dS \qquad (3)$$

The term on the right-hand side in (13) is a volume-integral which is obtained by the aid of the generalized theorem of Ostrogradsky (See Vaschy, *Théorie de l'Electricité*, 1896, p. 66).

The first of the two ways of evaluation is by means of the surface-integral,

$$8\pi F = \int_S P_0 \, dS \qquad (25)$$

and the second is by means of the volume-integral

$$2\pi F = -\int_V H^2 \operatorname{grad} \mu \, dv \qquad (26)$$

Since the permeability, μ, has been assumed to be constant, we have, in the iron, grad $\mu = 0$, except at the surface S, where $\operatorname{grad}_S \mu = N (\mu - \mu_0)$. For each surface element, dS, the volume integral, it will be recalled, will receive the contribution

$$(P_0 - P) \, dS = N (H, H_0) (\mu - \mu_0) \, dS$$

where the subscript zero refers to the surrounding medium. But the Maxwellian elemental effort being given (outside of the factor $1/8\pi$) by the value of the quantity P_0 under the integral sign in equation (25), in air, it is clear that the quantities to be integrated in (25) and (26) cannot both give the true elemental effort. It is commonly admitted that the quantity under the integral sign in (26) corresponds to the true effort, so that the Maxwellian effort P_0, considered as an elemental effort, appears

7. In formula (10') of my paper, the last term should be

$$-\frac{1}{m_n^2} \left(\frac{\cos \gamma_1}{\lambda_1} + \frac{\cos \gamma_2}{\lambda_2} \right) \text{ instead of }$$

$$-\frac{1}{m^2} \left(\frac{\lambda_1}{\cos \gamma_1} + \frac{\lambda_2}{\cos \gamma_2} \right)$$

to be fictitious, and it leads merely to the same resultant effort as (26).

For the condition μ = constant, formula (26) becomes, in effect,

$$8\pi F = \int_s (P_0 - P)\, d\, S \qquad (26')$$

But, by virtue of theorem (13), when integrating along the *inside* contour (the iron side) of the *closed* surface S, (since grad μ then vanishes) we have,

$$\int_s P\, d\, S = 0,$$

and we thus see that (26′) actually becomes identical with (25) for any closed surface.

If we consider $-\dfrac{1}{8\pi} H^2$ grad μ as the true effort per unit of volume, we can then scarcely attribute any real meaning to the Maxwellian stresses except in so far as they can be applied in the case of a surface of integration that is entirely closed.

The same remarks apply to the efforts deduced from the variation in the reluctance, which do not prevent us, of course, from assembling the efforts represented by tubes when these are considered component parts of the total effort.

STARTING CHARACTERISTICS AND CONTROL OF POLYPHASE SQUIRREL-CAGE INDUCTION MOTORS[1]

(Norman)

New York, N. Y., February 10, 1926

B. F. Bailey: I should like to point out the use of the follow ing formula

$$\eta = \frac{0.142 \times \text{Lb-Ft.} \times \text{Sync. Speed}}{\text{Volt-Amperes}}$$

in which η is the volt-ampere torque efficiency. By substituting the input to the motor in watts for the volt-ampere input we have the watt–torque efficiency. This formula is of course correct for any speed of the motor, although it is most useful in computing the starting efficiency.

In the case of a squirrel-cage induction motor the starting efficiency will usually be about 20 per cent. The wound-rotor induction motor will show higher values and a high-resistance; squirrel-cage motor still higher values. Split-phase induction motors have starting efficiencies of about 10 per cent.

This formula gives us a ready means of comparing the starting performance of different types of motors.

It can readily be shown that the starting torque of a polyphase motor expressed in synchronous watts is equal to the input to the rotor, but the demonstration is based upon the supposition that we have a rotating field which does not change shape as it rotates. In practise, the field does change its shape somewhat and in fact there may be backwardly rotating components of the field which directly subtract from the torque. In addition, there is some loss of torque due to bearing friction. The result is that the torque as measured by a brake is always somewhat less than the torque as computed from the input to the rotor. My experience has been that usually the actual torque will be from 85 to 90 per cent of the theoretical torque, although instances are common where somewhat higher or lower torques are developed.

K. L. Hansen (communicated after adjournment): Aside from containing useful suggestions and formulas, Mr. Norman's paper assists materially in advancing problems pertaining to the transient phenomena of acceleration and retardation from the rough approximation stage on to a sounder, mathematical foundation.

Under the assumption of negligible resistance load, the author has found the secondary copper loss, when accelerating from slip s to slip S, to be

$$\text{Watt-seconds} = 0.00744\ (M\ I)\ N^2\ (s^2 - S^2)$$

And the primary copper loss to be the secondary loss multiplied by $\dfrac{r_1}{r_2}$.

In the October 18th, 1924 issue of the *Electrical World*, I published the following formula for the secondary copper loss: (on account of lack of space, derivation of formulas was not shown)

$$W_s = \frac{W\ G^2\ N^2\ (s^2 - S^2)}{4324} = 0.000231\ W\ G^2\ N^2\ (s^2 - S^2)$$

where the moment of inertia $W\ G^2$ is expressed in lb-ft. changing to poundal-ft. by introducing gravity acceleration 32.2, it becomes

$$W_s = 0.00744\ (M\ I)\ N^2\ (s^2 - S^2)$$

which is identical with the one in the paper. An interesting point in this connection which Mr. Norman does not seem to mention in his paper is that, when accelerating from standstill the secondary; loss is equal to the energy stored in revolving parts.

In discussing motors in intermittent service, I made the following statement in my article:

"Comparing (3) with (1), it will be seen that when a motor accelerates from standstill to synchronism, the secondary energy loss is equal to the stored energy and the primary loss is the stored energy multiplied by $\dfrac{r_0}{r_1}$. As the secondary loss is independent of, and the primary loss inversely proportional to the secondary resistance, it follows that the ratio of secondary to primary resistance should be as high as the rate of acceleration permits in order to reduce the energy loss of the system to a minimum."

It will be noticed that this paragraph covers substantially the discussion on the second and part of the third page in the paper.

It might also be of interest to know that I have used the author's speed–time formula and found it satisfactory in applications where the resistance load is small and the inertia load is high, as, for example, in centrifugal extractors. When there is an appreciable resistance load in addition to the inertia load, however, other formulas give better results.

P. L. Alger (communicated after adjournment): Mr. Norman has given us a complete synopsis of the starting behavior of an induction motor. As he points out, the object of studying starting conditions is to design the motor and the control so as to secure minimum losses at starting and a reasonable, but not excessive, factor of safety in design.

To bring out some of Mr. Norman's ideas more emphatically, there are two points which seem to be worthy of mention. Both of these points arise from the fact that a motor designed primarily for starting duty should have different characteristics from one designed for steady operation. In order to obtain the best starting torque per ampere, it is necessary to have a high rotor resistance, and, in order to obtain low starting losses, it is necessary to have a low primary resistance. These two things naturally result in the designer's making a starting motor with few primary turns and therefore with a very high magnetizing current.

A high magnetizing current results in an appreciable difference between the primary and secondary currents during the starting period. Though Mr. Norman suggests that this difference can be neglected, it is often quite appreciable. As Professor Bailey stated in his discussion of the paper, the torque efficiency, defined as the ratio of the starting torque as measured with a

1. A. I. E. E. Journal, February, 1926, p. 153.

brake to that as calculated from the copper loss due to the measured primary current and the measured secondary resistance, is usually appreciably below unity. If the secondary resistance used in calculating the torque is the apparent value obtained by dividing the primary input at standstill, less the primary copper loss, by the square of the primary current, the torque efficiency is 100 per cent. But if the true value of secondary resistance is used, the calculated value of torque will be too high, due to the secondary current being smaller than the primary current.

Thus, in the attempt to make a motor with good starting characteristics, the magnetizing current is exaggerated, and so the accuracy of the simple theory which neglects magnetizing current may be said to be less, the better the motor is for starting duty. Mr. Norman, also points out that the existence of eddy currents in the rotor during starting again makes the theory less accurate and generally requires some approximations to be employed in calculating the primary copper loss. These eddy currents are exaggerated, in the attempt to obtain high starting resistance and low starting current without too seriously impairing the running efficiency by the increasing employment of the double squirrel-cage type of winding. However, if a double squirrel cage is so designed as to obtain the maximum possible starting resistance with a given running reactance, expressions for the secondary resistance referred to primary of the form $\frac{R}{S} + \frac{S X_0}{1 + S^2}$, and for the secondary reactance of the form $X + \frac{X_0}{1 + S^2}$, may be employed in place of the simpler ones, $\frac{R}{S}$ and X, and, with their aid, accurate formulas similar to Mr. Norman's may be derived for the time of starting and other characteristics.

H. M. Norman: In answer to Prof. Bailey's remarks concerning what he calls efficiency of the starting torque, I should say that there is nearly always a discrepancy between the measured starting torque by brake and that indicated by the watts loss in the rotor at start. The brake value is sometimes lower and sometimes higher than that given by the secondary loss. However, the average value obtained from a large number of different motors showed that there is only about a four per cent difference.

It should also be remembered that there is difficulty in measuring the input watts correctly, and also in estimating the proper value of the primary resistance (variation due to temperature) to use for calculation of the watts in the primary so as to obtain the correct watts loss in the rotor. In view of these difficulties, the best guide is the average of a large number of motors.

I think this is a very important point because it touches on the accuracy of the loss formulas in the paper. If it were true that this starting efficiency were appreciably below 100 per cent then the starting losses would be greater than the formulas in the paper indicate.

If there is no unbalance of phases, however, then it is my opinion that any adjustment of the constant 0.00744 in the loss equations need not exceed the addition of the four per cent already mentioned.

In reply to Mr. K. L. Hansen's remarks, I think it unfortunate that the same formula should have to be worked out independently at two different times, but in this case it has the comforting feature that we are both in exact agreement.

Regarding the fact that when starting from rest and accelerating to synchronous speed the secondary loss is equal to the stored energy of the system (this includes the energy of all the moving parts). I should like to point out that I purposely avoided mentioning this fact as it is subject to misuse for the following reason. Suppose that for a given system on account of the nature of the application the rotor of the motor has high resistance so that the full-load speed is say 90 per cent of synchronous speed. Then if the secondary loss be taken as equal to the stored energy of the system, it would be found to be 81 per cent of what it would have been had the system been accelerated to synchronous speed. This is not true, however, as the loss in the rotor under these conditions is equal to 99 per cent of this value.

This error is approximately equal to twice the full-load slip and even for low-resistance rotor motors is not altogether negligible.

Fig. 1 herewith gives a diagrammatic representation of the proportions of loss in the rotor of the motor and the stored energy of the moving parts. Consider a motor that has been accelerated from rest and has reached a speed proportional to $F\ C$ on this diagram where $F\ A$ represents synchronous speed. The area $F\ C\ D$ bears the same ratio to the stored energy of all the moving parts as the area $D\ E\ G\ F$ bears to the loss in the rotor. These areas become equal if the motor starts from rest and accelerates to synchronism so that for this particular case (*and this particular case only*) the loss in the rotor equals the stored energy of the moving parts.

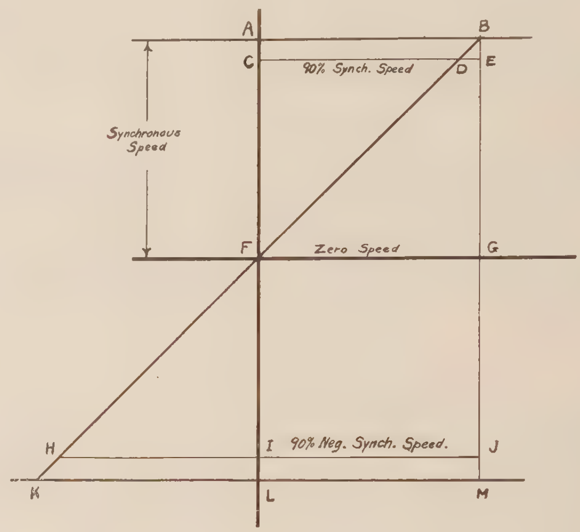

FIG. 1

This diagram also shows the ratio of lost and stored energy to the loss in the rotor when the rotor is plugged by extending the diagram into the negative-speed region. If a motor is running at say 90 per cent of synchronous speed and is plugged, the rotor reversing to 90 per cent synchronous speed in the reverse direction then, (referring to Fig. 1,) the energy lost in the moving parts by bringing them to rest is represented by area $H\ F\ I$, the energy gained by bringing the moving parts up to 90 per cent synchronous speed is represented by area $C\ D\ F$, and the energy lost in the rotor by area $D\ E\ J\ H$.

Referring to Mr. Hanson's statement that the short paragraph in his article covers substantially the discussion in part of my paper, I should point out that on the second page immediately following the loss formulas, I made a statement of approximately the same length and more or less equivalent to that in Mr. Hansen's article, and as I did not repeat myself in the subsequent paragraphs, I cannot see that his claim is well founded. Further, where there are only a few cycles of operation per minute I do not agree with Mr. Hansen's statement that the secondary resistance should be as high as the rate of acceleration will permit in order to reduce the energy loss to a minimum. This is neglecting entirely the losses during the running period. There are so many different cycles of operation that it is not desirable to

compile an abundance of formulas to give the best value of secondary resistance for each, but as there is one cycle which is perhaps the most common, I might add the following formula:

$$r_2 = \sqrt{\frac{0.00744\,(M\,I)\,N^2\,(1 - S^2)\,r_1}{\phi\,I_2^{\,2}\,t\,K}}$$

(For inertia starting loads only)

Where

I_2 = Secondary load current.

r_2 = Value of secondary resistance which gives the minimum losses over an entire cycle consisting of a start from rest to speed of $N\,(1 - S)$ and a full-load run for a time $= t$ (seconds) and a shut-down of any length of time. The constant is the ratio of effective resistance at start to that at full load and is slightly greater than unity.

The value of r_2 as obtained from this formula is for the load condition, $K\,r_2$ being the effective resistance at start.

Mr. Hansen seems to understand that I say that my speed-time formulas applied to all types of loading conditions. However, the method by which they were evolved, combined with the paragraph on the last page of my article drawing attention to friction or hauling loads, shows this impression to be incorrect.

In reply to Mr. Alger's statements, I should like to point out that the object of making the secondary resistance high for motors which are used for frequent starting is two-fold. It not only reduces the starting current, but also reduces the total losses during acceleration. The reduction of the primary resistance by means of reducing the primary turns has little or no affect on the starting losses, however, when measured in joules, and motors intended for frequent starting may sometimes be designed by changing the secondary winding only.

Motors to be used for special starting duty can be built with either a high rotor resistance, few primary turns to strengthen the field, or a combination of both, depending on the nature of the application.

If the starts are very frequent then the first method gives the best results as the starting losses are lowered and this results in a lowering of the total losses over a complete cycle of operation provided the rotor resistance is not increased excessively.

If the number of starts are very few and high starting torque is required on account of, say, excessive static friction, then the second method can be used provided the increased starting current is permitted and that low power factor is not of any great consequence.

When there are limits placed on the starting torque and current and the full-load power factor and efficiency, then the combination of more rotor resistance and fewer primary turns is used to meet these requirements. Again it may be used when the application requires high starting torque and a medium number of starts and stops.

From this it can be seen that the designer does not always use few primary turns.

Regarding Mr. Alger's statement that the use of few primary turns exaggerates the magnetizing current and so upsets the simple theory that during acceleration the primary and secondary current can be considered of equal value, I cannot agree. Neglecting saturation, the magnetizing current changes inversely as the turns squared. The starting current also changes in the same ratio. Therefore, the ratio of these currents is the same no matter what the primary turns may be. Should saturation be taken into account, then the consequent increase in current applies much more to the starting current than to the magnetizing current during acceleration because at start the main field is only one-half or one-third of its value at synchronous speed, while the leakage paths are saturated.

The difference between the primary and secondary current of the motor of average size and speed is about three per cent so that the value of the secondary resistance as given by formula (1) in the paper is about six per cent too small. Since the secondary loss (measured in joules) during acceleration is independent of the secondary resistance, then this error does not effect the rotor loss.

Now consider the primary loss during acceleration: the exact value could be obtained by multiplying the secondary loss in watts by the ratio of the primary resistance to the true value of secondary resistance and then by the mean square of the ratio of primary to secondary current over the starting period.

It so happens that this ratio of the mean square over the entire starting period is very nearly equal to the ratio of the square of the primary to secondary current at the instant of starting which is also the ratio of the true value of secondary resistance to the value obtained by using formula (1) in the paper. Therefore, by using formula (1) to get the secondary resistance and assuming the primary and secondary currents equal, very little error is introduced.

To illustrate how negligible this error is, consider a 50-h. p., 6-pole, 60-cycle motor. The ratio of the mean squares of the primary and secondary currents up to 90 per cent synchronous speed is equal to 1.041. The ratio of the true value of secondary resistance to that calculated by formula (1) is equal to 1.031, so

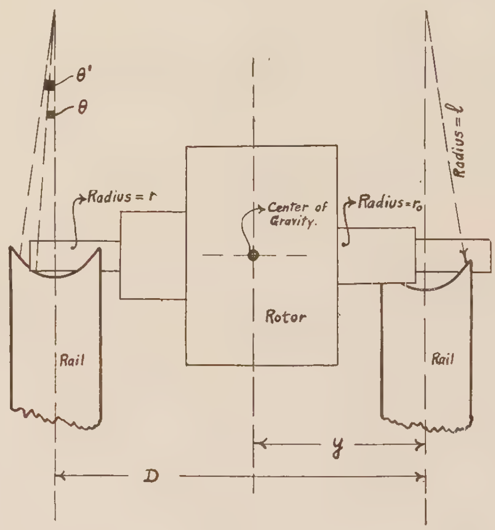

Fig. 2

that there is only one per cent error in calculating the primary loss. Consider an extreme case of a 50-h. p., 20-pole, 60-cycle motor with only 4¾ times starting current and 68 per cent full-load power factor. The ratio of the mean currents to 90 per cent synchronous speed is equal to 11.37 and the ratio of true to calculated secondary resistances is equal to 11.17 which shows that there is less than two per cent error even in this extreme case. From this it is obvious that it is sufficiently accurate to use the method given in the paper.

Mr. Alger seems to be under the impression that the work on reversing motors, in which I made correction for eddy-currents in the rotor, had something to do with a difference in the primary and secondary currents. This is not so; the reason for finding the primary loss by the method worked out in the paper was on account of a varying ratio between primary and secondary resistance while retarding the speed.

Regarding the statement that similar formulas to those given in my paper could be worked out for double-cage windings, I think that these formulas would be very complicated and therefore would not be extensively used. Further, it is doubtful if

such a motor would have any advantages over a high-resistance rotor motor as the higher full-load efficiency is misleading, the true guide being the total losses over a complete cycle of operation. Also there would have to be a decided advantage in favor of a double-cage winding to warrant its use as it is more complicated and expensive.

I should like to add the following formula which gives the radius of gyration for rotors which have journals with bearings of different diameter on each end. This measurment can be made by using the circular rails illustrated in Fig. 7. Squirrel-cage motors have usually the same diameter of bearing on each end but it is sometimes necessary to know the radius of gyration of other rotors. This can be done with the same equipment. Referring to Fig. 2 herewith

let

v = vel. of center of gravity of rotor.

R = radius of gyration radially (feet).

R_1 = radius of gyration about axis perpendicular to the shaft and through the center of gravity.

ω and ω_1 are the respective angular velocities.

Then gain in kinetic energy

$$= \frac{1}{2} M v^2 + \frac{1}{2} M R^2 \omega^2 + \frac{1}{2} M R_1^2 \omega_1^2$$

Loss in potential energy

$$= M g (\theta'^2 - \theta^2) \left[\frac{1}{2} \left(\frac{r_0}{r} \right)^2 (l - r_0) \left(1 - \frac{y}{D} \right) + \frac{1}{2} (l - r) \frac{y}{D} \right]$$

Substituting $\omega_1 = \omega \dfrac{r_0 - r}{D}$

$$\omega = \frac{l}{r} \frac{d\theta}{dt}$$

$$v = \left(\frac{D - y}{D} r_0 + \frac{y}{D} r \right)^{\omega}$$

Equating these two quantities and integrating gives:

$$R = \sqrt{\left(\frac{P}{2 \pi l} \right)^2 g \left[r_0^2 (l - r_0) \left(1 - \frac{y}{D} \right) + r^2 (l - r) \frac{y}{D} \right] - \left[r_0 \left(1 - \frac{y}{D} \right) + r \frac{y}{D} \right]^2 - \left[R_1 \frac{r_0 - r}{D} \right]^2}$$

The term $\left[R_1 \dfrac{r_0 - r}{D} \right]^2$ can be neglected.

From this equation it can be seen that the short-cut method which suggests itself of taking the average of r and r_0 and then substituting in the formula given on the tenth page of my paper does not give sufficiently accurate results.

Discussion at Madison Convention

TESTS OF PAPER-INSULATED HIGH-TENSION CABLE[1]

(Farmer)

Madison, Wisconsin, May 7, 1926

W. S. Clark: In connection with the figures given in Mr. Farmer's paper, one should not lose sight of the fact that there is no insulation of which we know in which the strength increases in direct proportion to the increased thickness of insulation.

The company by which I am employed makes small static condensers or capacitors for power-factor correction. These are operated with a stress of about 300 volts per mil, the total thickness of insulation being about 4 mils. We have found that if we desire to increase the voltage from 1200 to 2400 volts on these condensers, to secure the same factor of safety and freedom from breakdown it is necessary to more than double the thickness of the insulation.

In a general way the strength of saturated paper insulation, assuming uniform quality, appears to increase only about as the 0.8 power of the thickness and not directly as the first power.

With reference to the test referred to in Mr. Farmer's paper, regarding formation of wax or X compound in oil, the test as at present specified apparently cannot be duplicated in different laboratories with the same material. When the test is brought to a condition in detail where it can be duplicated in different laboratories with the same results, then I think it will be good.

E. C. Willman: We noticed that the X compound was greatest at the surface and in the layers of paper nearest the conductor; that is, at the point of highest stress. We therefore attempted to form the compound by stressing petrolatum placed between variously shaped electrodes, but without success. With the thought in mind that occluded air might be responsible for the formation, we tried bubbling ozone through melted petrolatum. This did not produce any X.

Later we dissected a piece of badly wrinkled cable which had a deposit of X in the wrinkles in the lead,—the point of least stress,—and had only traces at the conductor. This led us to believe that the formation was due to electric stress in combination with rarified atmosphere. We then made up a Geissler tube of glass 8 in. long and ¾ in. in diameter. An electrode was sealed into one end and the other end was provided with a rubber stopper through which an electrode and a smaller glass tube were inserted. Some petrolatum was placed in the tube, which was then exhausted to 28 in. of mercury and potential from a one-in. spark coil was applied to the terminals of the tube. In a short time the peculiar granular structure of the X compound became apparent on the surface of the petrolatum. Its identity was established by chemical and microscopic tests.

D. M. Simons: To my mind, the outstanding point of this paper is Fig. 7. If the breakdown strength of three-conductor cables under long-time application of voltage is only half that of single-conductor cables, or even if it is considerably less than single-conductors while not being as low as this figure suggests, then this is a fact of outstanding importance in the cable industry. I am interested in it not only for its general bearing, but also because it is a point that the engineers of the company with which I am associated have been claiming for many years, especially in connection with the use of three-conductor Type H cable in place of the usual belted construction for the higher voltages, say, 22,000 volts and higher. This form of cable is of course equivalent in its electric field to three single-conductor cables under one lead sheath, and our claim has been that this form of cable would avoid many of the troubles that have been observed in the outer layers of conductor insulation and especially in the filler spaces of the usual form of three-conductor cable and joints when used in the upper range of voltage. It is very significant to have this effect confirmed in such a striking manner by Mr. Farmer.

Percy Dunsheath: Mr. Farmer referred to the relative importance of the cable and the other part of the installation. The cable is, after all, from a financial point of view, *the* part of an installation to watch for possible improvement with a view to cutting down the costs of development work.

One point I should like to make is that the first thing to do is to settle this question of acceptance tests. If we can arrive at a

1. A. I. E. E. Journal, May, 1926, p. 454.

test that will prove quality, then I think quality will follow. If there has been any delay in improving quality, it has been because we have not known what we wanted and have not been able to recognize quality when it already existed. We are still using the standard pressure test in spite of the fact that after a cable has been pressure-tested in a factory, if it isn't a good length of cable, the pressure test may leave it on the point of breakdown and it is sent out of the factory in this condition.

Unfortunately, after the completion of these three papers we are not left with a clause which we can put into a specification,—an acceptance clause; but I think we are all agreed that the work, particularly Mr. Farmer's analysis of the time–voltage curve, does bring us very much nearer arriving at a clause of this kind. I don't know whether it has been done before (to me it is quite new) but I see that Mr. Farmer has analyzed the time–voltage curve into a number of component time–voltage curves, some for the bad parts of the cable and some for the good. I think that that is a very important observation to make because if a cable consists of a number of different parts, some with a low time-voltage curve and some with a high time–voltage curve, then a short-time, high-pressure test is a means of finding out weakness in the cable. If there is only one time–voltage curve for the whole cable, then a short-time high-pressure test can be carried out but it may be destructive.

Page 8 of Mr. Farmer's paper advocates adopting a standard load. Generally speaking I think that that is a good thing. If we could have a standard load which we could put onto any method of measuring losses,—dynamometer, bridge, or any other means,—and so arrive at a distinct, definite calibration, it would be a considerable step forward. I should suggest, however, that instead of the type of load which he proposes and which has to be measured, itself, we adopt a load which can be built up to a known power factor. I should suggest a condenser with negligible loss combined with a definite pure resistance.

On the eleventh page of Mr. Farmer's paper, those curves showing the variation of rising power factor with time are important and interesting and I am wondering whether the rise which he sometimes gets and sometimes does not get is due to a very slow increase of hydrostatic pressure. If so, possibly we can follow out that line with a view to getting an acceptance test, a cable which didn't give that original rise being a better quality than one which did.

Mr. Farmer describes the end which he uses for a three-conductor cable. I should just like to set forth a suggestion which I found useful in taking off ends for that type of test. To avoid the cost of a wiped joint, I have used ebonite cones about ½ in. thick, with a taped joint. Over the thickened dielectric on each core, I have carried tin-foil clear up to the crotch, with the result that no breakdowns can take place in the crotch. It is quite easy to bring an end of this kind to the highest voltage required.

I agree that the preparation of these samples is important. It is really astonishing the differences one can get on time—voltage tests on the same make of cable by first inverting the cable and putting the ends in oil, then turning the ends upward and putting on oil pockets. If anything should be standardized, it should be the method of making the ends. If an end is made which prevents the escape of any gases generated, up goes the time–voltage curve.

R. J. Wiseman: Referring to Fig. 1 of the paper, we find existing a rather interesting property aside from the wide variation in insulation resistance. The variation is very much greater for the compounds giving high values of insulation resistance.

Fig. 4, showing the distribution of failures for five-minute tests bears out what some of us believe; namely, that failure on a reel test is due to mechanical defects and will be detected with a reasonably high voltage. Too few tests are reported for 15 min. to be able to draw any conclusions. It is quite likely that Mr. Farmer is right, that, due to pre-testing by the manufacturer, failures on short time are eliminated before inspection.

Table I shows an improvement in breakdown voltage for each year; but there is still room for improvement. When the maximum dielectric strength at the conductor approximates the dielectric strength of a sample between flat plates we shall have reached the limit.

Figs. 5 to 10 inclusive are of interest in suggesting the limiting stress we can put on a cable indefinitely. At the present time, for methods of manufacture I believe 125 volts per mil is nearer the safety limit of operation than 150 volts per mil. This will give a factor of safety of about four or five on strength of material.

Mr. Farmer's suggestion of a standard load for checking dielectric-loss testing equipment is a very good one; besides the load he describes, I should like to advise his considering a load giving larger charging currents and higher power factors. I have found this important in making check tests on equipment.

A study of the change in power factor with time for different stress values is one of the best means to determine the aging quality of a cable. We would expect a slight increase in power factor for about 50 hours and then either constant or decreasing values.

I hope Mr. Farmer will be able to solve for us the proper manner of preparing samples of cable for high-voltage test. At present we do not get the real short-time breakdown voltage due to flashovers. Potheads are of great help but still not sufficient. The time consumed in preparing ends for test is enormous. Any means of reducing it and still permitting of higher voltages is welcome.

I should suggest that Mr. Farmer replot Fig. 30, using the maximum voltage stress at the conductor. Even though he may not think it accurate, he will get a better comparison of the test on cables and condensers for wax formation.

W. A. Del Mar: Unfortunately, the test for X which is described in Mr. Farmer's paper is open to the serious objection of giving discordant results. A case which came up quite recently was in relation to a barrel of compound which we had had in our laboratory for some weeks. We took out a sample which we designated A, divided it in two, sent half to the Electrical Testing Laboratories and kept the remainder ourselves. The Electrical Testing Laboratories sent back a report, "Abundant wax formation." Our laboratory, using apparatus as described in Mr. Farmer's paper, reported "none"; so we thought we would make a check test. We took another sample B out of the same barrel, again divided it in two, sending one part to the Electrical Testing Laboratories and keeping the remainder ourselves. They reported no wax and our laboratory reported considerable wax.

That bears out the general condition we have in our own laboratory; *i. e.*, we cannot obtain consistent results. We get X in a given compound perhaps in three or four tests in succession, and then, for some unknown reason, without any apparent change, the opposite result is obtained.

Even if the test can be perfected so as to be susceptible of unfailing check, insufficient evidence has been offered to connect the test with operating results.

Another interesting feature of Mr. Farmer's paper is the apparently greater dielectric strength of insulation on single-conductor cables as compared with triplex cables, as shown in his Fig. 7. This diagram, however, shows maximum stresses, as computed from the ordinary logarithmic formula. Recent researches by P. L. Hoover[2] have shown that the maximum stresses at failure cannot be derived from that formula, and that average stresses are a better criterion. As the average stress in a single-conductor cable is a much smaller fraction of the con-

2. *The Mechanism of Breakdown of Dielectrics*, by P. L. Hoover, A. I. E. E. Journal, September 1926, p. 824.

ventional maximum than in a triplex cable, the discrepancy which is made to appear in Fig. 7 disappears.

F. A. Brownell: For testing purposes Mr. Farmer has pointed out the need of an end bell that could be constructed or connected in a minimum of time. This is one of our chief difficulties at the factories today and it seems that more time and thought should be given to this subject. We have used, with some modification, the end bell shown in Fig. 22 of Mr. Farmer's paper and have had very satisfactory results, the only objection being the time required for wrapping the conductors with varnish cambric. I believe this can be overcome by the use of the roll of tapered paper that the Pirelli Company used in making up the joints on the 45-kv. line of the United Electric Light and Power Company of New York City. This paper could be made up into rolls and placed over each of the three conductors and tightened. This would give a snug-fitting insulation and the crotch would be entirely filled. It may be that the taper of the paper would have to be changed somewhat to give the desired fitting.

F. M. Farmer: First, I desire to make two corrections. In the advance copy printing the note under Fig. 7 refers to Fig. 12. This should refer to Fig. 6. In the captions for Figs. 25, 26 and 27 the word "wax" was used. This is unfortunate, since the product produced is not wax in the sense that the term is used in industry. In fact it is quite different from any known substance familiar to oil technologists and has none of the characteristics of any variety of wax. Furthermore, it is not soluble in any of the ordinary solvents. Mr. Del Mar has suggested the expression X. In view of our lack of knowledge of this substance, this designation seems particularly appropriate.

From the tests which he describes, Mr. Willman implies that this deterioration is due to the action of ultra-violet light resulting from a sufficiently high electric stress across microscopic air voids in the compound. Whether this X formation is due directly to the application of stress or due to the action suggested by Mr. Willman, which, in turn, requires the presence of stress, is, from a practical standpoint, immaterial to the user. He is interested in knowing whether or not the compound in the cable remains stable under the conditions of use which involve only two variables, namely, stress and temperature.

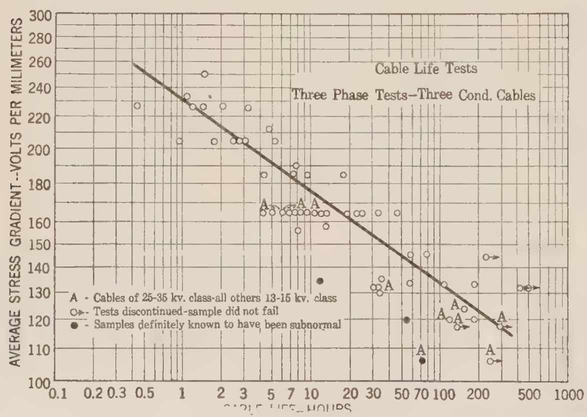

FIG. 6A—CABLE LIFE THREE-PHASE TESTS—THREE-CONDUCTOR CABLES

Mr. Del Mar has indicated that the test proposed for X formation is not dependable. It is probably true that it is not very sensitive where the compound forms X with difficulty so that X is formed at one time and not at another. Just why this variation occurs we do not know as yet but it is believed that the test being so simply and easily made justifies its use as a rough indicator of the probable performance of the compound.

Mr. Del Mar also raises the point that it has not been definitely demonstrated that this kind of deterioration in compound in a cable necessarily results in ultimate failure. This is true, but while we haven't positive proof that X in cable is objectionable, there is altogether too much circumstantial evidence available to justify engineers assuming that X is *not* objectionable. Since compounds can apparently be developed which do not form X and which are otherwise satisfactory, it seems only good engineering to avoid the use of X-forming compounds, even though we are not positive that they are objectionable.

Referring to Figs. 6 and 7, some additional data have been obtained since these diagrams were made and new diagrams are given herewith,—Fig. 6A corresponding to Fig. 6 and Fig. 7A

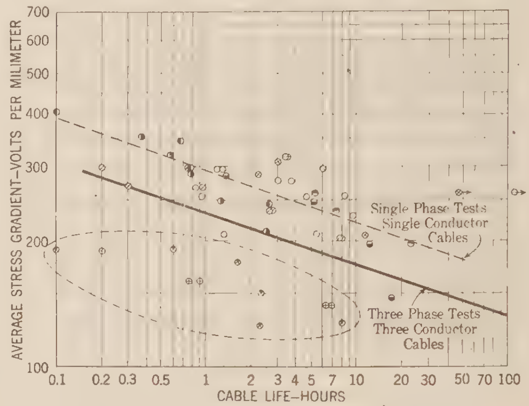

FIG. 7A—CABLE LIFE TESTS—SINGLE-CONDUCTOR CABLE

corresponding to Fig. 7. It will be observed that the slope is the same so that we are quite convinced that the seventh-power relation is approximately correct for at least the types of cable involved in these tests. Of course, if there is a pronounced change in the method of construction or in the kind of compound used in high-tension cables, the slope of these curves will undoubtedly be affected.

The point mentioned by Mr. Simons,—namely, the apparent superior showing of single-conductor cable over three-conductor cable,—is obviously of great importance; so much so, in fact, that a rather elaborate systematic investigation is being planned with specially constructed cable to determine the correctness or otherwise of this indication. Mr. Del Mar points out that if average stress instead of maximum stress had been used in preparing these diagrams, the apparent difference between single-conductor and three-conductor cables would have been less. This, of course, is quite correct. For instance, the average *maximum*-stress gradient to give a life of 10 hr. in three-conductor cable is 215 volts per mil and in single-conductor cable, 400 volts per mil, or an apparent increase of 86 per cent. The average *average*-stress gradient to give a life of 10 hr. is 175 volts per mil in three-conductor cable and 220 volts per mil in single-conductor cable or an apparent increase of 26 per cent. But which of these two bases is the true measure of dielectric strength of the cable as a whole? As we all know, there has been much discussion of this point and papers have been presented before this Institute giving evidence which apparently favors both of these gradients as well as intermediate ones. Eventually we shall have the true answer; and while it is highly probable that it will not be the maximum-stress gradient, it is also probable that it will be something higher than the average gradient. It seems reasonable to conclude, therefore, from the evidence presented here, that the inherent dielectric strength of single-conductor cable is on the average substantially higher than that of three-conductor cable and that the difference may be of the order of 40 or 50 per cent. However, as previously stated, this apparently large difference must be confirmed by further investigation before a final conclusion is justified.

Referring to Capt. Dunsheath's suggestion in connection with the proposed standard load for dielectric loss testing that various power factors be obtained by the use of series resistance, I should say that we have had this point in mind.

THE EFFECT OF INTERNAL VACUA[1]

(Del Mar)

Madison, Wisconsin, May 7, 1926

Wallace S. Clark: In connection with Mr. Del Mar's paper it should be remembered that the Pirelli idea is to keep in the cable, at all times, a pressure in excess of atmospheric pressure.

Percy Dunsheath: I think Mr. Del Mar has gone a little bit too far although probably not intentionally. I am rather afraid the impression that his conclusions will give is that all cables for high voltages should be supplied with oil ducts. I don't think he intended that and certainly I should resent any such suggestion, because I am sure that our experience with 33,000-volt cables, unhappy as it was years ago, today proves definitely and quite conclusively that a 33,000-volt cable can be made to give satisfactory service without oil ducts, whatever conditions of high voltages are called for.

R. J. Wiseman: Mr. Del Mar has presented to the public the views some of us have had for some time as to the effect of voids in cables. However, I think it would have been better if he had eliminated reference to atmospheric pressure. Voids are created in a cable due to the oil contracting as it cools and endeavoring at the same time to maintain a balanced pressure. This means that if a cable is sealed and the oil cools, it is below atmospheric pressure. A cable in operation with sealed ends is rarely at atmospheric pressure, usually above, and below only when cooled.

The size of voids in a cable will depend a great deal upon the type of oil and the freedom of motion. The size of the voids increases as we lower the temperature. This results from the capillary attraction of the oil to the paper. A tacky oil holds best and is likely to produce small voids rather than large ones, the latter being more objectionable.

Fortunately, shortly after a cable is installed at 0 deg. cent., it assumes the temperature of the ground and therefore heats up, eliminating most of the voids produced at low temperature. It is most desirable to load a cable up for a few days after installing it in order that the oil may become stabilized locally before making any voltage tests. Here the purchaser could help very well by actually putting a cable into service for a week and then making the acceptance test. This should be done on all high-voltage cables.

Take the case of the cables when they cool down after the load is removed, but the voltage is still on. Here it is advantageous that the dielectric loss be sufficient to heat the cable a few degrees, thus preventing the formation of voids. This brings out an important point. A reasonably low dielectric loss at low temperatures is preferable to a very low loss.

Creation of voids in joints is most probably due to the draining of the oil into the cable. It is not a case of stabilizing pressure, but rather improvement in cable impregnation. In such a case, the heating of the cable with load does not help the joint. The joint is on the way to failure unless refilled.

Herman Halperin: The impression is given in the paper that transient voltages cause many cable failures. In meetings of the A. E. I. C. Subcommittee on High-Voltage Transients on Underground Cable Systems, no information was given to show that transients cause any deterioration of the insulation. As expressed at a meeting of the subcommittee a few weeks ago, the opinion seems to be that the transients cause failures at unusually weak spots in the insulation; that is, the cable has usually been found obviously deficient at the point of failure, which cannot be said about cable failures in general.

1. A. I. E. E. Journal, July, 1926, p. 627.

The failures due to transients have generally been distributed over all parts of the underground systems, and rarely have they been located at any particular point, as may be inferred from the paper. This experience has been reported by several companies and is checked by the experience of the Commonwealth Edison Company.

In recent klydonograph investigations of surges on eight large systems, it was found that 85 per cent of the surges were less than twice normal voltage. About 1 per cent of the surges exceeded four times normal voltage, and it appears that surges must reach this magnitude to be disturbing. The latter surges may be slightly in excess of the full-reel test voltage at the factory. On the other hand, samples of high-tension cable will usually withstand test voltages of 7 to 12 times rated voltage of the cable for about one minute. The duration of the transient voltage is only a fraction of a second and Peek and others have presented data to show that the dielectric strength of insulation increases very rapidly as the time is reduced to a fraction of a second. One manufacturer has reported a case where the insulation withstood transient voltages of about three times the breakdown voltage he had been obtaining on dielectric-strength tests on samples. In regard to the decrease in dielectric strength on account of the higher frequency of the surges, it appears that this is more than counterbalanced by the increase in dielectric strength due to the shortness of the application of the transient.

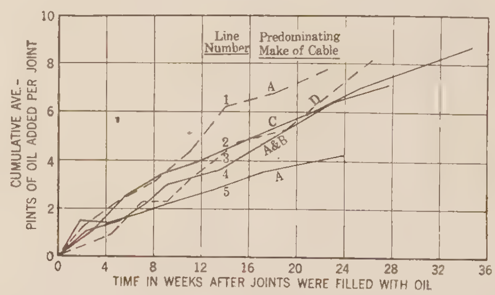

Fig. 1—Curve Showing Addition of Oil to 22-Kv. and 33-Kv., Three-Conductor Oil-Filled Joints With Insulation Formed

In general, with cable of high quality, such as indicated as being desirable in the paper on the Quality Rating of High Tension Cable by Mr. Roper and myself, evidence seems to show definitely that transients will cause no failures or have any deleterious effects on the insulation.

In regard to the point in the first paragraph of the paper, that sections upon removal from ducts will withstand severe high-voltage tests even though they have failed in service, the failure occurred at the spot of lowest quality. These weak and irregular spots have been found repeatedly in accelerated life tests in Chicago, and the experience has been that if a portion a few feet long were removed from a section of cable, the voltage rating of the section would then be increased from 15 per cent to over 100 per cent. In the last part of the paper, there are listed the essential characteristics for successful high-tension cable, but the item of uniformity is omitted, although experience shows that it is of paramount importance.

In connection with expansion and contraction incidental to the operation of cables and the consequent formation of voids, the Commonwealth Edison Company has had an interesting experience with oil-filled joints on several lines of 22- and 33-kv., three-conductor, impregnated paper-insulated cables with fair impregnation. The joints were filled with a switch oil having a viscosity of about 200 seconds (Saybolt) at 25 deg. cent. Periodically the joints were checked as to the level of the oil in them, and sufficient oil was added (or removed in a few cases) to restore the level to its normal plane. Fig. 1 herewith shows

the cumulative average number of pints of oil per joint added to these joints during the period of 5 to 8 months. In the average case, a total of about one gallon has been added in six months to each joint. This means that each length of cable had sufficient void space for one gallon of compound, which is sufficient compound to impregnate completely about 9 ft. of cable.

F. A. Brownell: Apparently Mr. Delmar's paper explains why so many of our cable failures occur during the off-peak when the cable is cooling or cool.

In 1923 we had 107 failures in our 13-kv. cables. Sixty-one of them could not be classified as to cause. Forty-two of this group failed during the early morning hours while the cables were carrying practically no load. Other years have shown similar results. If it is possible for vacua to form in our present cables at a temperature they would attain on an off-peak load, it would seem that this condition could be overcome by a rapid equalization of oil under pressure, the use of a less viscous oil than is used at present, and the installation of a reservoir on joints filled with the same oil that is used for impregnating the cables.

We have found the formation of X in cables operating at 26 kv., while in the laboratory it has required a potential of 100 kv., on the same make and type of cable before formation occurred. In cables impregnated with a rosin-content compound we were unable to produce it at potentials up to 210 kv. We have had cables that have failed in service operating at 26 kv. and have shown signs of ionization. This would indicate that the pressure in the cable must have been below atmospheric to have had ionization at this voltage.

D. W. Roper: Mr. Del Mar's theory seems to be borne out in a number of instances in our experience. He refers to the contraction of the compound in the cable; we have had a similar experience with compound in the joints. In some of our 33-kv. joints, we use a compound similar to that used in the cable; that is, a petrolatum. This particular line was operated practically without load for weeks at a time during the winter months. It was a tie line between generating stations and it was largely a reserve line on the generating capacity in the two stations.

After some weeks of operation during the winter season, we began to notice a bulging of the joints. We tried to discover the cause of this bulging, and as nearly as we could determine, it was due to the formation of small vacua or voids in the compound in the joint. Had this cable been operated every day at a load which would warm the compound up to the melting point, the voids, when they reappeared, would probably not have reappeared at the same location. You can find these voids if you will take a mass of compound, either in a can or a glass vessel, and expose it to low temperature; you will find small voids perceptible to the naked eye, distributed throughout the entire mass of compound. If you take a different kind of a compound which has more cohesion between the particles,—a more viscous compound,—then when the compound cools there will be more of a settling of the horizontal surface so that there will be a serious depression, but with a compound of this kind, there is no great amount of settling of the surface; the cooling occurs by the formation of these minute voids throughout the mass of the compound.

It appears that these small voids will occur now and then adjacent to the conductor insulation which is in the joint, and when these occur, the ionization, due to the discharge in the voids, will occur, and in the course of time these voids will enlarge. By careful examination of the joints when opened, we actually found some voids of approximately the size of the joint of the thumb, and adjacent to such voids, we found the evidences of ionization in the factory-applied insulation in these joints.

There was undoubtedly some pressure within these joints as shown by the bulging of the lead sleeve at the joint, although these lead sleeves were covered with broken cement, so that it not only stretched the lead sheaths but cracked the cement. The trouble has been cured by removing those joints so as to remove this petrolatum and refill with a thin oil. This is the oil referred to by Mr. Halperin in his discussion and diagram. No such trouble occurred when the joints were filled with oil; in fact, trouble could not occur in a thin oil which was so thin as to be fluid at even the minimum operating temperature of the cable. The nature of the compound used in the joint, as nearly as our experience shows, must either be fluid or be of a character which will not permit the formation of these internal voids throughout the mass of the compound.

T. F. Peterson: One must recognize that the burden of failures resulting from conditions characteristic of long jointed lines, must be borne by operating companies. Failure due to vacua in installed cable falls into this class. The following is submitted because it is thought that too much importance has been attached to this condition.

Spaces or air pockets in insulation may be due to:

1. Contraction of oil after impregnation
2. Expansion of lead due to bending
3. Contraction of compound due to cheese formation.

Mr. Del Mar makes no attempt to show the harmful effects of pockets containing gases at atmospheric pressure. Indeed he attaches no importance to these. Failures are considered to be due to the fact that *after* cables are installed, vacua are invariably produced, ionization takes place and ultimately failure results. This reasoning tends to exonerate the manufacture and shift cause of failure to a rather unfortunate condition with which operating companies must cope.

It is my contention that air spaces, even at atmospheric pressure, constitute a very important cause of failure (the action being somewhat slower than for vacua, nevertheless very pronounced) and since, in a large measure, they are due to causes 1 and 3, which are of manufacturers' concern, it follows that the latter must assume some part of the responsibility for failure. To substantiate this claim, consider the following:—Assume an air pocket at atmospheric pressure in a valley between turns of 5-mil paper; breakdown of this film, 0.0127 cm. thick, occurring at 68.3 kv. per cm. If the dielectric constant is assumed to be 3.5 the potential gradient in paper will be $\frac{68.3}{3.5} = 19.5$ kv. per cm. or 49.5 volt per mil. This is not an uncommon value for average gradient under operating conditions and so it appears that harmful results may easily result.

It remains, then, to explain the differences observed by the author between breakdown results on long and short lengths of cable. A partial explanation is given; namely, that of vacua. There is, however, another factor which tends to account for the results in-so-far as it assists the case of the short length. The latter is usually tested under oil where chances for reimpregnation are especially good; hence better test results.

The last paragraph of the paper gives ways of avoiding vacua. In the light of this discussion, it would seem that ways of diminishing possibilities of forming air pockets would have been a more appropriate subject for consideration.

W. F. Davidson (by letter): I am glad to note that Mr. Del Mar has attacked the problem of high-voltage cables from an angle which seems to be more in the direction of a real solution than many of our discussions of the "transient bugaboo." After all is said and done, our cables must be able to withstand such normal and transient voltages as do exist.

There is one phase of the paper which I wish to discuss; namely, the formula for this X or "cheese." When we have once definitely ascertained this factor we shall have made a long stride toward determining the true cause of its formation and definitely stating the effects of internal vacua, etc.

In the first place, I am surprised that it has been found possible to determine a chemical formula for X, because the original oils are known to be highly complex mixtures of several compounds and it is difficult to understand how we may be assured that the

resulting X is really one chemical individual. Until we have this assurance, a chemical formula has no significance. Possibly Mr. Del Mar can give his data.

In the second place, as I understand the processes of analysis used in such cases—assuming that we have proved the existence of a single chemical individual—we would obtain the oxygen ratio by determining what was left after the hydrogen and carbon have been determined. This should give a definite value for n.

Finally, we have no evidence presented to substantiate the statement that "it is apparently highly polymerized." Here it is necessary to assume again that the substance is a chemical, individual for it is usual to ascertain the degree of polymerization by determining the molecular weight; and a mixture of several chemical substances cannot have a single molecular weight. But even so, the determination of molecular weight seems almost impossible in the case of a solid substance which is non-volatile and almost insoluble.

J. A. Duncan (by letter): Mr. Del Mar's formula $(C_{12}H_{28}O)_n$ is of special interest to those of us who have been studying the deterioration of impregnating compounds and it is this formula which I wish to discuss. In order to include all possible interpretations of such a formula, one must discuss all possible values of n. This means all values of n from plus one to plus infinity, since zero or negative values have no meaning.

Let us begin with the case n equal to unity. The formula is then $(C_{12}H_{28}O)$, which is very remarkable, because 26 atoms of hydrogen alone completely satisfy all the available valency bonds in a single molecule of 12 carbon atoms and it is difficult, if not impossible, to imagine how the other two hydrogens and one oxygen are attached to the molecule. The straight chain structure in normal paraffins contains the maximum number of hydrogens possible if we attribute to carbon the valency four which, I believe, has always been found to be its maximum value. It is seen from the diagram of a paraffin (dodecane for example)

```
    H   H   H   H   H   H   H   H   H   H   H   H   H   H
H - C - C - C - C - C - C - C - C - C - C - C - C - C - C - H
    H   H   H   H   H   H   H   H   H   H   H   H   H   H
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that the maximum number of hydrogens per molecule is two plus twice the number of carbons. No carbon except the two at the ends of the chain can hold more than two hydrogens because two of its four bonds are occupied in holding the chain together. Each of the two end atoms holds three hydrogens.

The only way for a paraffin molecule to increase its oxygen content is for an oxygen atom to replace two hydrogen atoms or for a hydroxyl group O H to replace one hydrogen atom. In the former case, the hydrogen content is decreased and in the latter, it remains the same. If one O H group replaces a hydrogen in $(C_{12}H_{26})$ we should have $(C_{12}H_{26}O)$.

If one oxygen atom alone is placed within the molecule, it must replace two hydrogen atoms in order to find bonds for its two valencies. This would give us two hydrogens less than we had to begin with and the formula would be $(C_{12}H_{24}O)$.

It is thus highly improbable that one can have a compound with the formula $(C_{12}H_{28}O)$

If n had any value greater than unity, the case would be even worse because this would mean a molecule consisting of two or more groups of $(C_{12}H_{28}O)$ and one valence bond of each group would be occupied in holding the two together. The possible number of hydrogens too would be still further decreased. One of the first two terms of the formula must be incorrect or Mr. Del Mar has a new arrangement of the oxygen atom with valency greater than two or a carbon atom with valency greater than four. The only case I've ever heard of before where oxygen has a valency greater than two is in the so-called oxonium compounds; and I think it is true that the science has never known a case of carbon with valency greater than four.

Of course, Mr. Del Mar may not mean his formula as that of a chemical individual, but merely gives it to indicate the proportions of carbon, hydrogen and oxygen in a mixture of substances which he found in a cable. If we allow mixtures, we can mix the original oils in the cable in many ways which would give us any specified ratio of carbon to hydrogen from the ratio one-to-four to the ratio infinity; and we could add air, moisture, or moisture and air, to take care of any amount of oxygen from zero to whatever number of oxygen molecules there are in a cable.

It is fairly well known that mineral oils usually used in cables consist of mixtures of several hydrocarbons of various carbon contents.

For example, suppose we had any number of molecules of normal hexane C_6H_{14} and half of the same number of oxygen molecules in a mixture which we shall call A. The proportions of carbon, hydrogen and oxygen would be 12 to 28 to 1 as Mr. Del Mar indicates.

Or suppose we had any number of molecules of normal dodecane $C_{12}H_{26}$ mixed with an equal number of water molecules H_2O. Let us call the mixture B. The proportions of carbon, hydrogen and oxygen would again be 12 to 28 to 1.

Any mixture consisting of any amount of A with any amount of B would obviously still have carbon, hydrogen and oxygen in the proportions 12 to 28 to 1. Such a mixture we should properly call X, following Mr. Del Mar's happily selected notation.

Let us assume a cable oil with 0.1 per cent each of hexane and dodecane. One gram of this oil would contain 0.001 gram of each substance. Let p be the actual number of molecules of hexane and q the number of molecules of dodecane in 0.001 gram. Then

$$p = \frac{N}{86.112 \times 1000}$$

and

$$q = \frac{N}{170.208 \times 1000}$$

where N is Avogadro's number, Millikan's value of which is $(6.062 \pm 0.006) \times 10^{23}$ and 86.112 and 170.208 are the molecular weights of the two substances. One can have then a mixture of any number of molecules from (1 to p) of A with any number from (1 to q) of B and still have the proportions of carbon, hydrogen and oxygen indicated by Mr. Del Mar. The number of possible different kinds of X, no two of which are identical and each of which would fit Mr. Del Mar's formula is

$$p \times q = \frac{N^2}{86.112 \times 170.208 \times 1000 \times 1000}$$

or

$$p\,q = 2.5 \times 10^{37}.$$

The formula indicates no way except by guessing to tell which of the possible mixtures it represents. If each of the one hundred and ten million people in the United States would make a thousand guesses a day for fifty years this would be 2×10^{15} guesses. The chance of one of these guesses coinciding with Mr. Del Mar's X is a little less than one in 1.25×10^{22} or in other words one in twelve and half thousand billion billion and the guessing would be further complicated by the 99.8 per cent of the oil which we did not consider specifically in the above p and q.

C. F. Hanson (communicated after adjournment): In some localities, high-voltage cables operate at relatively low temperatures. From the point of view of dielectric loss and the possibilities of cumulative heating, these low temperatures of operation are considered favorable. However, from the point of view of internal vacua, these low temperatures are detrimental, if the cable is not permitted to "breathe."

The conditions upon which I base my calculations in arriving at the foregoing conclusions are as follows:

1. The maximum operating temperature of the cable insulation during summer months is 40 deg. cent. (104 deg. fahr.)

2. The minimum operating temperature of the cable insulation during winter months is 20 deg. cent. (68 deg. fahr.)

3. The temperature of the cable insulation at the time of installation during summer months is 30 deg. cent. (86 deg. fahr.)

4. The temperature of the cable insulation at the time of installation during winter months is 15 deg. cent. (59 deg. fahr.)

5. It is assumed that an internal pressure of one atmosphere is established throughout a length of cable while the ends of the cable are open for splicing purposes.

6. The impregnation of the cable is expressed in terms of per cent of air by volume based upon the total air in the cable prior to impregnation. The air content is considered to be that which prevails at 25 deg. cent. (77 deg. fahr.)

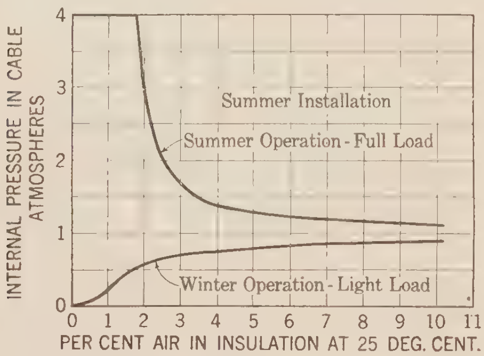

Fig. 2

7. The temperature coefficient of expansion of the impregnating compound is considered to be 0.1 per cent per deg. cent.

8. The internal pressure in the cable which will cause a permanent stretch in the lead sheath is considered to be 4 atmospheres. (Approximately 44 lb. per sq. in. gage pressure.)

9. The impregnating compound and the fibers of the paper are considered incompressible.

10. The temperature coefficient of expansion of the lead and of the copper is considered negligible, particularly in view of the fact that an expansion in the lead is partly counteracted by a simultaneous expansion in the copper conductors.

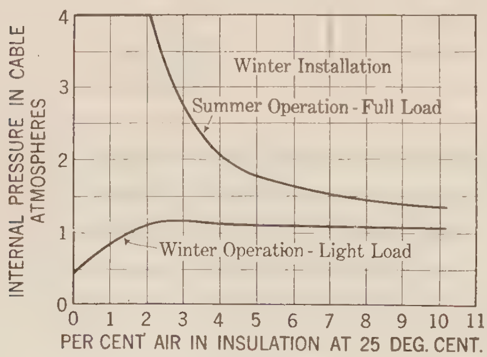

Fig. 3

11. A length of cable is considered sealed at each end by virtue of a non-flowing splicing compound.

12. The volume of air varies according to Boyle's law in regard to pressure.

13. The volume of air varies according to Gay-Lussac's law in regard to temperature.

Within the foregoing conditions, I have calculated for various percentages of air, the internal pressures which will prevail in a cable during maximum load in the summer and during minimum load in the winter when the cable is installed during summer months. The results of these calculations are shown in Fig. 2 herewith. I have also made corresponding calculations for a cable which is installed during winter months, and show the results in Fig. 3.

In Fig. 2, the lower curve shows that the internal pressure of the cable is always less than atmospheric during light loads in winter. If the ionization voltage of air is proportional to the pressure, then it is evident from this curve that a poorly impregnated cable is superior to a well impregnated cable. For example, if, in a cable of a particular wall and voltage, the ionization pressure is 0.8 atmosphere, then the cable having an air content of five per cent or more would operate without ionization. On the other hand, the cable having an air content of less than five per cent would operate during winter months with ionization which will produce carbonization.

If cables are installed during winter months, then operating conditions are more favorable in regard to internal pressure. A cable would have to be well impregnated before its internal pressure would be less than one atmosphere during winter operation. For example, only those cables having an air content of less than 1.5 per cent would have an internal pressure of less than one atmosphere during light load in winter. The reduced pressure in this case is brought about by a permanent stretch in the lead sheath. The permanent stretch is produced during heavy-load periods in summer.

A comparison of Figs. 2 and 3 indicates that when non-flowing splicing compounds are used, winter installation is more desirable than summer installation. Furthermore, the curves in these illustrations, indicate that cables deteriorate mostly in winter, particularly if the cables are installed in summer.

It is not advocated that cables should always be installed during winter months. Winter installation is only a means for partly alleviating the unfavorable conditions caused by the use of non-flowing splicing compounds. The proper installation is that which will permit a cable to "breathe" as the temperature of the cable changes. Such installation is exemplified in the present-day use of very liquid splicing compounds and the application of syphons.

W. A. Del Mar: The principal discussion of my paper has taken place in the personal meetings and correspondence before and since the Madison meeting, and I have been surprised and gratified by the great interest manifested.

As I intimated in my paper and as repeated by Mr. W. S. Clark, there is nothing new in the basic ideas presented, but the implications which bear on ordinary cables seem to have been ignored almost completely by operating men and manufacturers alike. If any manufacturer had these ideas clearly in mind, his duty to the industry was to pass them on without delay to the cable users. So far as I know, this was done for the first time when I gave copies of a memorandum on this subject to several members of the Underground Systems Committee of the N. E. L. A., nearly a year ago.

We all recall the classic 1919 papers by Shanklin and Matson,[2] and Dubsky,[3] wherein it is shown that films of air entrapped in a cable ionize at an insulation stress of about 19 kv. per cm., but perhaps we neglected to note, as the three authors named above were silent on the subject, that this stress applies to air at atmospheric pressure only.

We recall, moreover, the work of such experimenters as Peek, proving that the ionization stress of air is approximately proportional to the air pressure.

Combining these researches, we obtain Table I, showing the

2. Transactions A. I. E. E., 1919, p. 489.

3. Transactions A. I. E. E., p. 537.

relation between ionization stress in cable insulation, and air pressure.[4]

We are now equipped with an important tool which, in our hands three years ago, might have saved the electric power industry and the cable manufacturers a considerable amount of worry. In order to understand this, consider the matter in Table II, which shows the maximum stresses for several typical triplex cables and the air pressures required to prevent ionization at these stresses, taken from Table I. The table may be summarized in a few words:

Cables of the 13,000-volt class do not ionize even though the pressure may be somewhat below atmospheric.

Cables for 22,000 volts have an ionization pressure of about one atmosphere.

Cables for all higher voltages as listed require an internal pressure of between one and two atmospheres. This is a conclusion of great importance which seems to have escaped the attention of the industry. It is well known that cables for over 22,000 volts belong in a different class, from an operating standpoint, from those for lower voltages. The former have had either excessive failures or at least show deterioration of the insulation, except in a small minority of cases. The latter give little or no trouble.

TABLE I

Air pressure, atmospheres	Relative ionization voltage as fraction of that at 1 atmosphere (Peek)	Ionization stress taking 19 kv./cm. for 1 atmosphere
0.1	0.2	3.8
0.2	0.3	5.7
0.5	0.53	10.0
0.7	0.70	13.3
1.0	1.00	19.0
1.25	1.22	23.2
1.50	1.44	27.4
2.0	1.90	36.1
2.5	2.35	44.7

TABLE II

TRIPLEX 350,000-CIR. MIL CABLES

Working voltage between phases, Kv.	Insulation each conductor, 64ths in.	Maximum stress, kv./cm.	Internal pressure required to prevent ionization, atmospheres
13	12	16	0.8
13	9	19	1.0
22	19	20	1.0
22	18	21	1.1
24	18	23	1.25
26.4	18	25	1.35
27.6	19	25	1.35
33	19	30	1.65
33	23	26	1.40

Similar information for single-conductor cables is given in Table III, from which it appears that cables for 132-kv. circuits with 60/64-in. insulation require about 3½ atmospheres, which is near the limit of strength of an ordinary lead sheath.

It is also a curious fact that the trouble seems to increase the more carefully the cable is made. This is because of the difference in impregnation; the more thorough this is, the greater the vacua due to contraction. This has been very clearly brought out by Mr. Hanson's discussion. For this reason, some of the cables of five years ago seem to be more reliable than those of today.

The effects of ionization in the order of their occurrence are—formation of X, carbonization of oil, formation of dendritic patterns, and eventually failure. The action may, however, stop at any point, as cables are in operation which have been full of X for years and carbonized oil has been known to exist for years in cables without further deterioration, probably because of increased internal pressure.

Let us consider what has been done by operating engineers to influence the internal pressure of high-voltage cables.

First, they have written specifications which compel the furnishing of "over-saturated" cables, *i. e.*, cables in which high vacua are formed if operated as they have been in the past.

Second, they have done most of their installation work in summer, thereby insuring the occurrence of vacua in winter.

Third, until recently they have used splicing compounds which seal each length of cable and make pressure equalization impossible.

Fourth, they have given no consideration to the installation and operating conditions which influence internal pressure, thereby leaving the pressure to take a chance value which might or might not permit their cable to survive.

It seems necessary to put a definite predetermined pressure on high-voltage cable insulation and maintain it with scrupulous care. Forward-looking practise points to the use of spindle oil splices and syphons. I believe that by this means some cables which have had their operating voltages lowered due to continual failures will be successfully restored to their rated voltages.

TABLE III

SINGLE-CONDUCTOR 500,000-CIR. MIL CABLES

Working voltage to ground, Kv.	Insulation, 64ths in.	Maximum stress, kv./cm.	Internal pressure required to prevent ionization, atmospheres
23	40	24	1.3
26	40	27	1.5
43	52	38	2.1
43	60	35	1.9
76	60	62	3.4

When all high-tension cables are equipped with pressure gages and pressure-maintaining devices, the guarantee clauses in cable specifications will assume a legitimate significance. Mr. Petersen sensed this point very clearly in his discussion.

I agree with Mr. Dunsheath that all high-tension cables do not have to be supplied with special oil ducts, as it is possible to maintain adequate pressure in most cases by relying upon natural interstices in the cable.

My paper supports Mr. Halperin in his views about transient voltages, by furnishing an explanation of certain failures which, in the past, have been blamed on transients.

Mr. Petersen's explanation of the higher breakdown voltage of short lengths as compared with complete feeders,—namely, that oil from the terminal tanks is sucked into the cable,—cannot be correct, both because the opposite action occurs due to the heating of the cable, (*i. e.*, the cable oil is expanded and driven out), and because the same relation holds if the short lengths are tested without oil terminals or tanks.

Mr. Brownell has brought out an interesting point in mentioning that X forms more readily at 26 kv. in service than at 100 kv. in the laboratory.

Mr. Davidson seems to have taken my formula for X more seriously than I had intended. I used a formula only because the results of analysis as percentages are hard to visualize. The

4. If the air films are very thin, this relation does not hold; but experience shows that it is approximately correct for most of the films of the dimensions found in cables.

evidences of polymerization are to be found in high specific gravity, solidity, insolubility, and infusibility considered in connection with the known origin of the material.

Mr. Duncan's discussion of my formula for X is very much to the point. He shows clearly that the suggested formula is untenable, and I am rather inclined to believe that the explanation is that the oxygen atom is superflous. We can now form X in such vacua that it seems that no atmospheric element can enter into its composition. The chemists obtained the oxygen by difference and not by any positive test, so that its existence is at least open to doubt. The formation of X is preceded by an apparent increase of surface tension, *i. e.*, the oil acts as if its surface tension had increased very greatly, causing it to form into drops. Perhaps the polymerization which characterizes X formation is a result of this surface tension; *i. e.*, it may be nothing but a further drawing together of the molecules.

Mr. Roper's and Mr. Halperin's discussions add important material to our general store of knowledge on this subject. There are more of this kind of data which bear on pressures and vacua in cables to be gathered from the experience of operating engineers. For instance, it has been found that splices which are equipped with unweighted syphons have a lower breakdown voltage than identical splices without the syphons, and some people would interpret that as indicating that the syphons might be an objectionable feature. The explanation as furnished by one of the earliest users of syphons is that splices tested with them are at atmospheric pressure inside, whereas those tested without them, being heated by the dielectric losses, have an internal pressure which may be very considerable. The internal pressure naturally increases the dielectric strength and raises the breakdown voltage at the splice. The obverse of this is seen in the trouble experienced with both cables and joints where vacuum joints have been used.

A full realization of the significance of cable vacua and pressures should materially assist in the design of cables for much higher voltages than now considered practicable, without departing from the diameters which ducts and handling difficulties now impose.

Discussion at Niagara Falls

CIRCULATION OF HARMONICS IN TRANSFORMER CIRCUITS[1]

(Lennox)

Niagara Falls, N. Y., May 27, 1926

D. C. Prince: There are, in general, two ways of regarding such waves as those set up by commutating devices whether of rotating or static character. Fig. 4, in Mr. Lennox's paper, is typical of the waves encountered. Such a wave may be regarded as made up of a series of constant-amplitude waves of different frequencies, as Mr. Lennox has done, or it may be regarded as a succession of simple states.

From this latter point of view, the wave shown consists of direct-current portions joined by portions of constant slope. Both these states must independently obey Kirchoff's laws. This enables the wave forms, at least in the simpler networks, to be made up, taking into account the various impedances.

In particular, the transition portions of rectifier waves have as their driving force the impressed sine-wave so that the transition currents are sine waves of fundamental frequency superimposed upon either steady or decaying direct currents. These lend themselves readily to quantitative analysis where the harmonic analysis may present some difficulty.

From the point of view of inductive interference, some error may be invited if the analysis method is used. For instance, a square wave under harmonic analysis may give waves of all frequencies which are multiples of the fundamental. Some of the frequencies with the indicated amplitudes might set up objectionable interference. Physically, however, the inductive effect is in the form of impulses sent out at half-cycle intervals. These impulses set up a series of damped wave trains in a resonant circuit or simply a series of pulses in a circuit damped beyond the critical point. Neither of these responses is necessarily objectionable. The difference is that, when a wave is analyzed, the effect of all the components must be included. Many of these will have cancelling effects which might be lost sight of in treating any given problem by harmonic analysis.

A FLUX-VOLTMETER FOR MAGNETIC TESTS[1]

(Camilli)

Niagara Falls, N. Y., May 27, 1926

R. L. Sanford: For the determination of the average value of an alternating electromotive force a rectifier of some kind is necessary. While somewhat difficult to keep in good working condition, the rectifying commutator, either mounted directly on the generator shaft or driven by a synchronous motor, has been, up to the present time, the only satisfactory apparatus for the purpose. The commutator has a number of disadvantages which are obvious to any one that has had occasion to use it and the development of a really satisfactory method for measuring average volts represents a distinct advance in the art.

The device described by Mr. Camilli has the advantages of simplicity and portability. While the evidence of its reliability presented in the paper seems to be fairly conclusive, it was felt that a really crucial test would be a direct comparison with the rectifying commutator using a sine wave of voltage and also with various degrees of distortion. This was done at the Bureau of Standards. In making the test, the commutator brushes were adjusted for rectification at the zero point on the wave and its condition was checked by noting that the reading of an a-c. voltmeter was the same whether connected to the source directly or through the commutator. The average volts were read by means of a Brooks deflection potentiometer and a volt-box. Simultaneous readings were taken by different observers with the potentiometer and the flux voltmeter, and the values in all cases agreed well within the limits of the allowable error. It appears, therefore, that the flux voltmeter measures average volts with a satisfactory degree of accuracy and should prove to be a very useful instrument for a number of purposes.

As pointed out by Mr. Camilli, the total core loss with a distorted wave is somewhat high, as the eddy-current loss is proportional to the square of the effective voltage rather than to the average voltage. He has indicated an indirect method for making the correction. It would appear better, however, to determine the correction directly by making measurements with different degrees of distortion, noting the effective voltage in each case. The correction can then be made by simple calculation. This method has the advantage that no assumption as to the ratio of eddy currents to hysteresis is necessary.

W. H. Cooney: Any one who has endeavored to obtain a given core loss twice on the same transformer when using different generators on each test with consequent variations in wave form will appreciate the development of a meter which will give consistent results regardless of how distorted or how near sine wave the wave form is.

In the past, many core-loss correction outfits have been based on setting voltage by an a-c. voltmeter, thus getting the r. m. s. value. Since, as Mr. Camilli pointed out, only the eddy loss is a function of the r. m. s. value, the correction which had to be made was almost entirely in the hysteretic component. That this was not the proper end from which to tackle the problem can be realized by considering the general proportion of hysteresis and eddy losses.

1. A. I. E. E. Journal, August, 1926, p. 755.
1. A. I. E. E. Journal, October 1926, p. 989.

Eddy losses are very rarely more than 20 per cent of the total loss and are usually much less. By the use of this scheme, which holds the average voltage corresponding to the effective sine-wave voltage desired, the correct hysteresis loss is maintained and the correction need be made only on the eddy component, which, as has been said before, is comparatively small.

Some of the previous core-loss corrections consisted essentially of a small "standard" transformer excited in parallel with the transformer under test, and one of two methods was used: (1) The available voltage was varied until the "standard" transformer held the desired core loss; or (2) the available voltage was adjusted to the desired root-mean-square value (regardless of the wave form) and the loss of the transformer under test was corrected in the same proportion in which it was necessary to correct the "standard" transformer in order to put the latter on a sine-wave basis.

The objections to the use of a small "standard" are quite apparent. The chief objection is that the "standard" is very seldom at the same density as the main transformer and thus is not operating on the same part of the density-loss curve which has a decided "knee" in it. It is necessary to maintain all sorts of calibration curves with the increased liability of introducing errors. There is finally the general objection that a small model in tests of this sort cannot be expected to duplicate the phenomena occurring in large apparatus.

The only correction which needs to be applied to this meter (for eddy loss) can be made very easily, as very few calibration curves will be necessary since the division of hysteresis and eddy losses can be determined closely enough for any given line of steel. The only possible case in which this meter will be inaccurate is where the wave goes through zero more than twice in a cycle, and this should never occur in commercial testing.

Aram Boyajian: The simplicity of the theory, construction and method of application of the flux voltmeter may tempt us to underestimate the excellent engineering which has been incorporated into this outfit. It is true that such parts of the outfit as d-c. voltmeters and vacuum-tube rectifiers have been available separately, and it is also true that the mathematical relation between maximum flux density and arithmetical average voltage has been known to the electrical art for a long time. It remained for Mr. Camilli, however, to bring together the theory and these pieces of apparatus into an outfit which accomplishes a new function in a new and very satisfactory manner. The accuracy and consistency of core-loss tests made with the aid of this outfit are surprisingly good, especially in comparison with the older schemes. The extent to which the older schemes underestimate the core loss under conditions of bad wave distortion will no doubt interest very strongly inspectors on acceptance tests as well as those engineers who draw up specifications.

T. C. Lennox: I should like to point out the advantage of this device for determining the core losses in interphase transformers for rectifiers. These interphase transformers have voltages which are not of sine-wave form and furthermore have different wave forms for different conditions of load so that it is difficult to obtain loss measurements which are representative of actual losses under load. The flux voltmeter could be very easily applied to obtain the actual flux densities under load conditions and thus aid greatly in obtaining a correct measurement of the efficiency of the equipment as a whole.

CURRENT TRANSFORMERS WITH NICKEL-IRON CORES[1]

(Spooner)

Niagara Falls, N. Y., May 27, 1926

I. F. Kinnard: In the design of current transformers, it has long been recognized that a core material having low losses and high low-induction permeability is desirable. It is undesirable, however, to have the permeability of a transformer core changing very rapidly over its working range.

Wonderful strides have been made in perfecting magnetic materials in recent years. The material described recently by Messrs. Arnold & Elmen[2] known as "permalloy" has properties which recommend it very highly for the use Mr. Spooner has outlined. Mr. Spooner has not given us any specific magnetic or metallurgical data on hypernik, but it probably can be assumed that it is very similar in its properties to the series of iron-nickel alloys described by Yensen[3].

Permalloy in particular, and, to a lesser degree, other iron-nickel alloys, partially fulfill the requirements of an ideal core material. The reason they do not more completely fulfill these requirements is largely due to their rapid change in permeability. In fact, at a fairly low induction the permeability falls off so rapidly that the accuracy of the transformer is seriously impaired, as pointed out by the author. This is particularly troublesome in the through-type or bushing transformers where the operating density is necessarily high with secondary burdens usually met with in practise.

It is to be hoped that further improvement may make it possible to utilize the remarkable properties of these various alloys to greater advantage; that is, that their range of usefulness may be extended to transformers having less than 200 ampere-turns which will operate secondary burdens up to at least 15 or 20 volt-amperes.

I am interested in Mr. Spooner's description of utilizing the coordinate a-c. potentiometer for measuring the magnetizing and watt components of the exciting current. This is a big improvement over most methods used in the past. I believe it is possible to extend this general method so that a strictly null setting may be obtained and the possible accuracy made even greater. We must not lose sight of the fact, however, that the real criterion of a transformer's performance is the precision measurement of its ratio and phase angle.

Several laboratories are equipped to measure these quantities directly to a higher degree of accuracy than we can hope to reach by their calculation from a knowledge of exciting current and magnetic properties.

W. K. Dickenson; The ideal toward which every instrument-transformer engineer is working is to obtain a minimum error in the ratio of transformation of voltage or current, particularly that part of the error commonly called the phase angle, which is caused by the secondary voltage or current not being in exactly 180-deg. phase opposition to the primary voltage or current.

In current-transformer design, this has usually been accomplished by the use of a relatively high number of ampere-turns (usually 1000 to 2000) and by a considerable cross-section of core iron. This materially limits the use of the through-type or single-turn-primary type of transformer, since, as there is only one turn available, the current has to be 1000 amperes or more to give a sufficient number of ampere-runs for a good transformer.

A very considerable improvement in the characteristics of transformers, particularly current transformers, has been obtained by the now very common use of silicon steels. It is very encouraging to note the further improvement in both the ratio and phase-angle errors by the use of high-permeability steels, such as hypernik and other nickel-alloy steels, such as nicaloi or permalloy. Mr. Spooner has shown that not only can the ampere-turns be reduced (he states a minimum of 200 ampere-turns) but the weight of core can also be reduced by the use of hypernik.

As pointed out by Mr. Spooner, however, it is to be regretted that only low secondary burdens may be operated by transformers having cores of these nickel-alloy steels, because of their characteristic of becoming saturated at quite low magnetic

1. A. I. E. E. Journal, June, 1926, p. 540.

2. *Journal* Franklin Institute, May, 1923, pp. 621-632.

3. A. I. E. E. Transactions, 1924, p. 145.

densities. It is unfortunate that in the particular application where the through-type or single-turn, primary type of transformer would be of greatest value, *viz.*, in large power stations, the secondary burden is likely to be fairly high, due to the necessary length of the secondary leads. These leads are seldom less than 100 ft. in length (200 ft. No. 10 A. w. g. wire equals 5 volt-amperes) and in one of the new stations in New York City the secondary leads are 1000 ft. in length, 2000 ft. of wire (50 volt-amperes for No. 10 A. w. g. wire).

It is to be hoped that means may be discovered that will enable us, through a wider range, to take advantage of the very encouraging results obtained by Mr. Spooner by the use of nickel-iron alloys.

Thomas Spooner: Mr. Kinnard is correct in assuming that hypernik is a nickel-iron alloy. The nickel content is approximately 50 per cent. Hypernik, however, is a very special alloy, in that it is made from very pure raw materials in a type of electric furnace which permits of no contamination. After being rolled to the proper thickness it is given a special, somewhat expensive heat treatment which was developed for this particular material.

Mr. Kinnard has perhaps misunderstood my purpose in using, to a large extent, calculated instead of test values for current-transformer performance. It was first shown that for through-type transformers, this is a reliable procedure. The calculated performance for a number of sizes of transformers was then determined, since this is much quicker than actually constructing the transformers and then testing them. If transformers are actually to be built, it is of course better to measure than to calculate their errors if accurate results are desired in order to take care of variations in the core material and, in any but through-type transformers, of the effect of joints in the magnetic circuit and of magnetic flux leakages.

Referring to Mr. Dickenson's remarks, while it is true that the nickel-iron alloys saturate at a considerably lower induction than do the silicon steels, the permeability of hypernik is nevertheless higher than that of the best laboratory-prepared silicon steel up to an induction of five or six kilogausses. This corresponds to a fairly large secondary burden, even for low-ratio through-type transformers, thus making hypernik superior to silicon steel even under these adverse conditions.

THE RETARDATION METHOD OF LOSS DETERMINATION AS APPLIED TO THE LARGE NIAGARA FALLS GENERATORS[1]

(Johnson)

Niagara Falls, N. Y., May 28, 1926

R. B. Williamson: The testing of large generating units after they have been installed in the power station is becoming more common than was formerly the case because the great increase in size has rendered satisfactory factory testing very costly; in many cases it is, in fact, impracticable because the machines are not completely wound and assembled at the factory. There is no doubt that a great deal of money has been expended in the past on unsatisfactory factory tests that could have been made to much greater advantage after installation. Any methods of testing, therefore, that are of advantage when machines have been set up ready for use are worthy of very careful study and we are much indebted to Mr. Johnson for the present paper which shows the application of the retardation method to some of the largest hydroelectric units so far built.

In factory testing the usual method of determining losses is by means of a calibrated driving motor, but this is often difficult to apply to large vertical units. When using a driving motor it is frequently difficult to hold the source of power steady enough to avoid periodic swings in the power input to the motor and this affects the accuracy of the readings. When large machines are tested in the power house by measuring the input with the generator operating as a motor supplied from a second water-wheel unit, the source of power is much steadier and correspondingly better results can be obtained. Even here, however, difficulties are sometimes met due to periodic variations caused by slight hunting of the water-wheel governor. One great advantage of the retardation method is that, after the machine has been run up to or slightly over speed, the driving power is cut off and all fluctuations due to variations in driving power are also cut off.

In applying the method to water-wheel units where it is necessary to leave the wheel connected and thus rotate the runner in the water-wheel casing, it is important that the casing be drained and also opened by removing the manhole covers. I recall one instance where a retardation test was being made and unaccountable variations were found in the speed. The casing had presumably been drained but the vents had not been opened and it was found that a considerable quantity of water was being thrown around in the casing. The manhole covers were then removed, the casing completely drained well below the level of the runner, and there was no further trouble.

As pointed out by Mr. Johnson, it is not essential that the fly-wheel effect of the rotating parts be known in advance provided means are at hand for measuring the kilowatts required to drive the machine as a motor at known speed. If the loss is thus measured, the fly-wheel effect for use in the other tests can then be calculated with a sufficient degree of accuracy. Usually, however, there is no difficulty in obtaining a close estimate of the fly-wheel effect from the manufacturer and the retardation tests are sufficient to obtain the losses by the methods described.

The analysis of the friction and windage of the three 32,500-kv-a. units in Table IV is of special interest. Unit *A X* as mentioned is equipped with shrouded steel-plate fans with curved blades, and baffles are provided to prevent eddies and short-circuiting of air around the fan. On account of the limitations imposed by the generator design, these fans have an efficiency considerably lower than that of regular blowers provided with a spiral casing, but at the same time it is true that a generator of this type with such fans and baffles will show in general less windage loss than one where the air is free to eddy around. Where the peripheral speed of the rotor is fairly high, as in the present instance, the difference in windage loss may be considerably in favor of the machine with fans as in Table IV, whereas the general feeling of many users is just the opposite, *i. e.*, that fans increase the windage loss. The spider arms of large generators stir up vigorous air currents which involve loss in power; hence shrouding the arms to cut off these currents is frequently well worth while.

It is of special interest to the designer to note that these tests indicate that the stray-load loss at a given speed varied as the square of the current. This, I believe, has been generally assumed to be the case and tests on many machines made by driving by means of a calibrated motor show this relation to be quite closely true. It is important, however, to have this confirmed by tests made on such a large generator and by a different method. The greater part of the stray loss is undoubtedly due to so-called eddy currents in the windings, but a considerable part is also due to stray induced currents in various parts of the machine structure caused by stray fluxes from the windings. It is fortunate, therefore, that notwithstanding the complicated make-up of the stray loss, it is found to be practically proportional to the square of the current.

We fully agree with Mr. Johnson that with the use of suitable instruments, such as he describes, the retardation method can be made of much more use than has been the case in the past. We also feel sure that with the more extended use of methods such as these, tests of machines after installation will supersede many of the factory tests now made on large or even moderate-sized

1. A. I. E. E. Journal, June, 1926, p. 546.

units, because such tests will be less expensive and very much more satisfactory.

E. M. Wood and G. D. Floyd: At the Queenston plant of the Hydro-Electric Commission, we have had the same problem of determining the conventional efficiency of large water-wheel driven alternators, and have in general solved it in a manner similar to that described by Mr. Johnson. Some of our conditions have been different from those described and have given rise to variants in the procedure, some of which may be interesting.

All our tests were made with the turbine uncoupled from the unit under test, as the units have two guide bearings. The units were started as described in the paper. Field current for approximately normal voltage at no load was required on each of two similar units for sure starting. Starting currents at times swung to ½ rated current of one generator of 55,000 kv-a. rating.

Manufacturers' calculations of $W R^2$ were taken but were checked by wattmeter measurement of input to the unit as synchronous motor, whenever the governor of the driving unit would hold speed sufficiently steady to give reliable readings. The calculation checked closely with the test values.

When conditions permitted this test, however, a complete curve of losses by wattmeter was taken down to approximately half voltage. Under proper conditions, these results are possibly more dependable than those from the retardation test but in most cases (but not all) the governor allowed the speed to hunt so that the results were of doubtful value.

The current transformers used were rated at about four per cent of the current rating of the generator and were connected across the blades of gang-operated disconnecting switches to protect them during starting and during changes of test conditions. A man was stationed at the switch with an ammeter and given instructions to close the disconnects quickly in case of a sudden rise of current.

On the first units tested, retardation tests were made using a stop watch and hand tachometer, varied by use of a tachograph and in some cases by use of a high-speed graphic voltmeter for the core-loss curves. We found these not very satisfactory for the reasons stated in the paper.

On the last three units tested, a Cambridge chronograph adapted by Messrs. Borden and Floyd was used. Two elements record on a tape the following:

1. One jog for each half-revolution of the generator.
2. One jog for each revolution of a machine running at synchronous speed (187½ jogs per minute).

From the tapes, speed-time curves were plotted, the rate of retardation at synchronous speed was found and the losses calculated. The average loss between one per cent above and one per cent below synchronous speed was calculated directly in most cases, as the average speed-time curve had been obtained very accurately between 110 per cent and 90 per cent of synchronous speed. In those cases where a curve of loss against speed was obtained, the loss at synchronous speed checked the calculated loss very closely.

The method of reading the record, tabulating the results and calculating the losses given in the paper is very neat and simple. The long intervals were apparently allowable due to the high fly-wheel effect and slow retardation. In our case, the intervals had to be much shorter. This could be varied by using longer overlapping intervals.

Curves of friction, windage and short-circuit losses were taken on one of our units by the retardation method with good results. The switching incident to this test is somewhat involved and must be carried out in a very short time, requiring careful preparation. In this test, it is of importance to observe the temperature of the armature windings.

Mr. Johnson's practise of running the retardation test to below 50 per cent of rated speed is new, and he has used it to obtain much interesting information.

V. Karapetoff: I am glad to hear a practical operating man recommend the retardation method because I have been urging its use for over 20 years. I learned about it in Europe where it has been used much more than here. The principal reason why, perhaps, it has not been used so much is that with small machines the rotating part stops too rapidly to allow an accurate measurement of retardation, and the second reason is the necessity for knowing the moment of inertia.

Of course these difficulties are not insuperable and those interested in this method will find both in the Continental and in the British literature, quite a number of ingenious and indirect methods of measuring deceleration and the moment of inertia. The general theory will be found in my *Experimental Electrical Engineering*, Third Edition, Vol. I, pp. 408-416.

Mr. Johnson suggests that a convenient and simple method be developed for directly measuring the rate of retardation. I wish to mention a condenser device which was proposed quite a number of years ago for measuring acceleration and deceleration of railway trains, and which, with modern measuring instruments, should be satisfactory for the purpose desired. Consider a capacitor connected to a source of direct voltage. Then we have the relation: $q = C e$, where q is the charge on the condenser, C is its capacitance, and e is the applied voltage. Taking a derivative of both sides of this equation with respect to time, we get $d q/d t = C d e/d t$. Call this current i; then $i = C d e/d t$.

Suppose that you have some device, such as a d-c. magneto generator, belted or otherwise connected to the generator under test, and let the induced voltage of this device be proportional to its instantaneous speed. Then $e = k v$, where v is the instantaneous velocity, and k a coefficient of proportionality. Substituting this value of e in the equation for the condenser current, we find that $i = C k (d v/d t)$.

The value of $d v/d t$ is the retardation of the machine, and the current flowing into or out of the condenser is proportional to it. In other words, if you have a magneto in series with a galvanometer and a condenser, the instantaneous indication of the galvanometer is a direct measure for the instantaneous retardation of the machine.

W. J. Foster: Mr. Johnson has described the retardation test and he has developed it, I think, to a higher degree of perfection than any other person.

There are three methods of testing large generators: the motor method, the retardation and the calorimetric. The first that I had experience with was the motor method and fairly good results were obtained, but it failed completely in the matter of the load losses or short-circuit losses. Since those losses have become very important the motoring method by itself is now obsolete.

The retardation method was developed and practised several years ago quite extensively in the shops of the General Electric Company. It was found to be a very convenient method when the speed could be determined with accuracy and the $W R^2$ from calculation, but when the rotor contained castings there were always some uncertainties about the $W R^2$.

In our work we sometimes found it well to obtain the speed electrically, which is especially easy where there are direct-connected exciters and a battery is used to excite the field so as to hold the excitation perfectly constant.

I regard the calorimetric method, however, as the coming method in most machines. Our hydraulic generators are going to become more and more totally enclosed and it is not in the far distant future when we will have the closed system, the same air being returned over and over again. So I think that the most accurate method and the method by which we will obtain the real efficiency will be the calorimetric method.

I say the real efficiency because the matter of taking the short-circuited losses as the load losses is an approximation to accuracy. It has been standardized and when it is used by the designers in calculations and in giving guarantees it, of course, should be measured in the test, and the total losses should include for load

losses the short-circuited losses. But by the calorimetric method the actual load losses are obtained and that is extremely important.

I think that in such generators as Mr. Johnson has worked with, where he has housings around them, he can very well check up the results obtained by the retardation method. I wish he would do so as a supplement before this paper is published in the A. I. E. E. TRANSACTIONS. It wouldn't take over two days on one of those machines to do all of it. He should vary the power factor of the machine under test from unity down to 80 per cent, and thus be able to furnish extremely valuable data for designers as well as for users.

I can't speak in too high terms of the work done by Mr. Johnson. I have been in contact with it somewhat and he certainly has used his brains.

It was just a trifle amusing to me to notice his remarks with reference to the unusual opportunities that he had in having three generators of different design and also some combinations of hydraulic turbines to work with.

No doubt the engineers of all of the manufacturing companies will agree that each has some compensation for the disappointment he experienced in failing to receive the order for all three units,—in the excellent test data and the improved retardation method furnished by Mr. Johnson.

Mr. Johnson discusses the effective resistance and gives formula (**8**). I wish to remind you that there are other losses, eddy-current losses in the magnetic material, and what is needed now is for data to be collected that will look towards the determination of the effects of end magnetization.

P. A. Borden: It is particularly interesting to learn that in his tests of generators, Mr. Johnson has been making use of the chronograph for the precise determination of speeds through a cycle of velocity values. A method almost identical with Mr. Johnson's was developed independently by the Hydro-Electric power Commission of Ontario, and since then has been employed in all its tests of large units where there was required a permanent and accurate record of all speed values during the time of observation.

L. A. Doggett: (communicated after adjournment): In connection with the study of the losses of induction motors supplied with non-sinusoidal electromotive forces, some retardation runs have just recently been made at the Pennsylvania State College. These runs were on machines of 5 to 20 h. p. Although these machines are pigmies compared to Mr. Johnson's 65,000-kv-a. unit, it would seem worth while to have on record some of the problems occurring at the other end of the scale of sizes.

First, as to speed measurements, it soon developed that the attachment of a tachometer, whether of the mechanical or electrical type so altered the friction that the retardation curve was materially affected. For example, where it took 52 sec. to reach zero speed without the tachometer, it took 37 sec. to reach zero speed when a tachometer of the electric type was applied to the end of the shaft throughout the run, all other conditions remaining the same. To avoid this error a stroboscopic method was used, in which an arc was supplied by a current of known frequency. The light from this arc was directed upon a disk attached to the shaft. On this disk were arranged in the usual way circular rows of spots at uniform intervals, such as 45 deg. and 30 deg. The time was noted when these spots reached apparent rest. With this arrangement very satisfactory speed-time curves were obtained.

Second, as to $W R^2$ measurement, this value was determined in two ways. The first is as described by Mr. Johnson and involved a separate measurement of the friction and windage at a definite speed. This in conjunction with the retardation run gives a value for $W R^2$, which for one five-h. p. induction motor was 2.36 lb-ft². A second value was determined by another method. In this method the rotor was removed from the stator and suspended vertically as a torsion pendulum and in this condition its time of swing was determined. The time of swing was again determined when an additional known $W R^2$ was attached to the rotor. From these data the $W R^2$ came out 2.26 lb-ft². The torsion pendulum method is considered the more reliable.

J. Allen Johnson: Several speakers have made suggestions as to the technique of the tests such as the necessity for draining the wheel case and opening vents, the use of disconnecting switches to short circuit the small current transformers during adjustments, etc. These are desirable precautions. Messrs. Wood & Floyd have used a generator running at synchronous speed to measure time. It would seem to the author that much more accurate means of measuring time are available in the form of clock mechanisms.

The electrical accelerometer outlined by Professor Karapetoff is extremely interesting and if it could be worked out into an instrument suitable for field use might be of value. At present it appears to the author as a scheme which might readily be used in the laboratory but hardly a tool for powerhouse use. It has, however, interesting possibilities, and the author looks forward to the time when the inherent merits of the retardation method will have created sufficient demand for such an instrument to justify some manufacturer in undertaking its development.

Anyone who has carried out retardation tests and has observed the almost majestic steadiness with which these huge machines slow down under the influence of their own losses, completely unaffected by any outside influence, will share with him, the author believes, not only his conviction that in this method we have something elemental in its simplicity and trustworthiness, but also his desire for a means of making the necessary measurements of speed and rate of retardation as simple and direct and elemental as the method itself. Such a means seems to be provided in the use of a chronograph, revolution counter and timer. The author doubts if he could have equal confidence in the results obtained by any method less simple and direct, such, for instance, as electrical tachometers or accelerometers involving the accurate knowledge of electrical constants and the necessity of accurate calibration.

Mr. Foster calls attention quite rightly to the fact that in measuring the short-circuit losses we are only making an approximation to the actual stray-load losses. The author frankly recognized this fact in stating in this paper that these tests were to determine the "conventional" efficiencies of the machines in question.

Mr. Foster proposes the calorimetric test to determine the *actual* load losses. The author sincerely hopes that successful results may be obtained in this manner, but confesses to some skepticism in the matter, when recalling a test of this character, in which he assisted, made on a 7500-kw. generator in 1905 or 1906. The losses by radiation, the difficulties in determining accurately the average temperature of large volumes of air and of determining the mass and velocity of the air are a few of the practical obstacles which the author sees in applying the calorimetric method. He agrees with Mr. Foster, however, that no other method of determining the actual stray losses seems possible, and the desirability of finding out what these losses actually are probably justifies considerable trouble in perfecting the calorimetric method. He is of the opinion, however, that nearer two months than two days would be required to get any worthwhile results on the large generators by this method.

Mr. Doggett's method of determining $W R^2$ by using the rotor as a torsional pendulum is very interesting. To apply this method to a rotor weighing 400 tons, however, would seem to invoke some practical difficulties.

VARIABLE ARMATURE LEAKAGE REACTANCE IN SALIENT-POLE SYNCHRONOUS MACHINES[1]

(Karapetoff)

Niagara Falls, N. Y., May 28, 1926

P. M. Lincoln: It would have added to our information if Prof. Karapetoff had gone a little further into the details of the amount of departure of this particular machine which he cites in the last part of his paper.

The reactance of our large machines is becoming very much larger than it was ten or fifteen years ago. At that time, internal reactance of generators was something of the order of 10 per cent —from 8 per cent to 12 per cent; nowadays, on account of the very much greater capacity of the machines, it is necessary to limit the amount of short-circuit current that will occur in order to secure safety in switching devices. And the best method of limiting of course, is to limit the reactance. The internal reactances of our large generators has gone from a matter of 10 or 12 per cent up to 15 to 25 per cent. It has more than doubled.

Now Prof. Karapetoff has indicated that this much larger internal reactance can be properly divided into two factors. One of them is a reactance which is independent of the position of the phase of the current-carrying coils with respect to the poles, and the other factor is a factor which depends upon that relationship.

I think it would add to the paper if Prof. Karapetoff would indicate the amount of departure between the tests and the assumption that the reactance is constant—how much is ΔL, what is the value of ΔL that he has discovered, what that relation is that it bears to the L.

E. B. Shand: Referring to Blondel's theory of two reactions, assume that the armature conductors of an alternator are carrying current of which the phase relation may be represented by the accompanying Fig. 1; the armature turns are concentric with the field winding so that they will either add to, or subtract

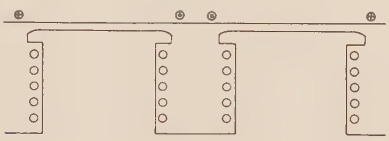

Fig. 1

from, the ampere-turns of the field. This component of current is that of direct magnetization. When the current is 90 deg. out of phase from the above condition, as is indicated in Fig. 2, the flux produced by the armature magnetizing force will pass into one side of the pole and out the other side. Thus flux has always presented some difficulty to me in the way of definition. If the ordinary transformer conception is adhered to, this flux, which

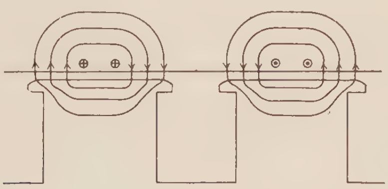

Fig. 2

does not interlink with the field winding, will be called leakage flux. On the other hand, the armature ampere-turns modify very materially the main flux of the machine and also may produce saturation effects so that it has always seemed to me that the definition "cross-magnetizing flux" in accordance with Blondel's ideas is the better term for it.

1. A. I. E. E. Journal, July 1926, p. 665.

Any analysis of the kind given in this paper is greatly dependent upon where the line is drawn between armature cross magnetization and armature leakage reactance. I should like Professor Karapetoff to give us his ideas on this matter and the assumptions he has made in connection with the paper.

J. F. H. Douglas (communicated after adjournment): Professor Karapetoff's article shows clearly how many factors must be considered in theory when accurately predicting the performance of a synchronous machine, factors which do not enter into the performance at zero power-factor.

His treatment of linkages of flux has the merit of rigor which

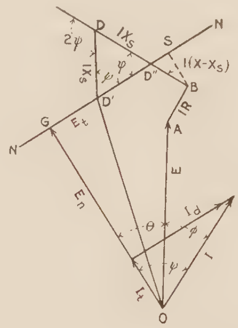

Fig. 3—Illustration to Prove that the Blondel Two-Reactance Diagram is Identical with the Diagram Including a Supplementary Reactance Drop

the arbitrary assumption of two "reactances" seems to lack. His equations (**8**) and (**9**) in conjunction with his Fig. 1 lead to an important relation

$$X_s / X = \Delta L / 2 L < 1/2 \qquad (1)$$

on which it would be interesting to have an experimental check. He shows clearly that by considering theoretically derived constants X_t and M_d, and the more usually known reactance, $(X - X_s)$, values of the torque angle θ and of the internal phase angle ψ may be considerably in error.

The graphical construction given in his Fig. 3 follows along lines advocated by me in the discussion of an article in the

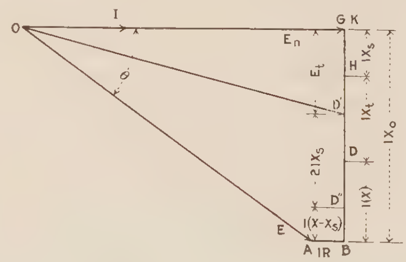

Fig. 4—Blondel Diagram for Condition of No Direct Reaction

A. I. E. E. Journal for Jan. 1925,[2] with the added advantage, of course, of including the factor X_s.

Fig. 2 of his article is susceptible of interpretation in several ways. It is important to note that one interpretation is not inconsistent with the two-reactance theory in general and that of Dr. C. P. Steinmetz noted in Footnote 4 in particular. Consider the accompanying Fig. 3, which is Fig. 2 in the article with the point S added. The lines $D\,S$ and $B\,S$ are

$$D\,S = I\,(X + X_s) \operatorname{Cos} \psi = I_t\,(X + X_s) \qquad (2)$$

$$B\,S = I\,(X - X_4) \operatorname{Sin} \psi = I_d\,(X - X_s) \qquad (3)$$

We may locate the $I\,X$ drop as $B\,D + D\,D'$, or as $B\,S + S\,D'$.

2. Douglas, Engeset and Jones, *Complete Synchronous Motor Excitation Characteristics.*

The latter interpretation of the figure is that the $I\,X$ drop consists of two separate components, (a) one caused by the direct component of the current I_d acting with a reactance, $X_a = X - X_s$, and (b) one caused by the transverse current I_t acting on the reactance $(X + X_s)$.

Another viewpoint might be to regard $S\,B$ as above and consider $S\,G$ as a sort of total transverse voltage drop, due to the transverse current I_t acting on the reactance $X_o = X + X_s + X_t$ using the notation of Karapetoff's equation (**15a**). Inasmuch as

$$X_o = X_a + 2\,X_s + X_t \tag{4}$$

it will be seen that to consider X_a and X_t and neglect X_s may result in considerable error. The graphical construction is in no way influenced by these interpretations but the theory becomes very much simpler, when we consider the constants M_d, X_o, and X_a, and disregard their components X, Xs and $X\,t$.

As is well known, the zero full-load saturation curve can be used to evaluate both direct reaction and armature reactance. The reactance evaluated is, I believe, that reactance I have called X_a, namely $(X - Xs)$. It would be most desirable to have an experimental method for the evaluating of the reactance $X_o = (X + X_s + X_t)$; the experiment which would be most useful would be to load a machine as an alternator, with a leading current such that the angle ψ was zero, that is, with the current wholly transverse. With this loading, the voltage terminal E, the torque angle θ, and the field current should be measured. Fig. 2 of the article then becomes the accompanying Fig. 4 below, and the reactance X_o and E_n can be computed by

$$X_o = (X + X_s + X_t) = (E \operatorname{Sin} \theta)/I \tag{5}$$

$$E_n = E \operatorname{Cos} \theta + I\,R \tag{6}$$

The value of E_n should check with field current I_f if the theory is correct, and the value of X_o could be obtained.

I wish to record the conviction that the attempt to separate Xo into components X, X_s and X_t, will be very difficult. First, physically, where shall we picture the $(X + X_s)$ linkages as ending and the X_t linkages as beginning? Experimentally X_o alone can be measured. If we calculate X_t theoretically from design data, and the residual $X + X_s$ is small, then there will arise the question whether our transverse coefficient is accurately known. For example, the whole effect could be attributed to an error in the theoretical derivation of the constant X_t. Stated in a somewhat different way, I could, with a single value of armature reactance X_a, and a somewhat larger value of X_t than Prof. Karapetoff uses, predict the same performance characteristics that he does, with the use of the three constants X, X_s and X_t. (I am referring to the phase angles θ and ψ, for the field current another constant, that of direct armature reaction would have to be used.)

Vladimir Karapetoff: In reply to Mr. Shand's question, I should say that from a physical point of view we have in an alternator a doubly excited magnetic circuit, which is excited by the field winding and by the combination of the polyphase windings on the armature. There is a complicated flux which varies in space and in time, and only part of which moves synchronously with the poles, the rest corresponding to harmonics moving at different velocities, some in the direction of rotation of the machine, some against it. Any division into various armature reactions and leakage reactances is only a practical makeshift which perhaps is not rational from the physical point of view. The best we can do here is to play the game straight and not figure out the same fluxes twice.[3]

The particular makeshift which Blondel proposed many years ago consists in resolving the armature currents into two components in time, one component which reaches its maximum when that particular group of conductors is opposite the center of a pole and the other group which reaches its maximum in the position midway between the poles. The magnetomotive forces due to these two components are considered separately and also in combination with the field m. m. f. For details see the references given above.

3. V. Karapetoff, "The Magnetic Circuit," p. 150; Doherty and Nickle, *Synchronous Machines*, presented at A. I. E. E. Annual Convention, White Sulphur Springs, June, 1926.

SAG CALCULATIONS FOR TRANSMISSION LINES[1]

(Dwight)

Niagara Falls, N. Y., May 28, 1926

M. G. Lloyd: I want to say something about the problem in general, and how it has been handled elsewhere. There are two ways in which it may come up.

In a line that is already constructed, if you know what your sag is, you can get the tension very simply by this formula (**2**) which the author has given and which expresses the tension in terms of the sag, the loading, and length of span.

I think the more usual case, however, comes up in the design of a line where you want to know how to string the wire so that under the worst condition of loading which it will experience or which may be assumed, it will not be stressed beyond a definite fraction of the strength. In that case you start out with your loading and with your definite tension and you want to find the sag. Formula (**1**) does that very simply for that loaded condition.

The construction man puts it up, however, under some other condition, and he wants to know what the corresponding sag is under stringing conditions, and that is the thing which gives a lot of trouble.

As the author here points out, by using these formulas, one can work back by a method of trial and error or successive approximations, or you can, using formula (**3**) and others, work out a number of cases and get a set of curves from which then you may be able to read off directly the particular value which you want.

I want to speak, however, of another method of doing that which we have found more simple and time-saving in the long run. And I might say that at the Bureau of Standards I think perhaps we have done as much sag computing as anywhere in the country, in connection with the sag tables and curves for the National Electrical Safety Code.

In an Institute paper[2] which I think we may call one of the classics on this subject, Percy H. Thomas showed how, in plotting a curve between sag and stress, one could represent what we might call a generalized condition, by expressing sag as a percentage of span length and applying the loading in unit terms. That corresponds to the first formula of the paper and it is all right for the simple case which does not involve conditions of changing temperature, because it is changing temperatures that bring in the greatest difficulty.

A little later, two students, Messrs. Melvin and Wynne at the Massachusetts Institute of Technology, with whose thesis work I presume Prof. Dwight is not familiar, pointed out how a series of curves could be plotted to assist greatly in solving this problem. They plotted a whole family of curves which apply to different loadings of a given material, and then plotted on the same sheet of paper, another set of curves which are the stretch curves at different temperatures. The two families of curves intersect. (They used the parabolic relation in getting these but in the later work we have used the catenary relation in order to have them more accurate.)

What we call the stretch curve will represent conditions corresponding to some single temperature when the load on the wire is varied.

Now suppose the load is entirely removed from the wire; (and in that load I include the weight of the wire itself); we come all the way down on the stretch curve to the axis (the limiting member of the sag-stress curve being comprised of two axes)

1. A. I. E. E. Journal, June, 1926, p. 564.
2. Trans. A. I. E. E. 30, p. 229 (1911).

just as though the wire had no weight or load, and could be strung without sag or tension.

In using the old Thomas method, one would compute what we are now doing graphically; that is, take the load off the wire, get the condition of the wire with no load, then assume a change in temperature and find the change of the unstressed wire in length due to change of temperature. Upon arriving at that new length at the new temperature, apply the load again and then find the condition of the wire in sag and tension

The method of using the new charts is this: Pick out the point representing the stress,—that is, the tension reduced to pounds per square inch,—and the corresponding sag. You find what that is for your loaded condition.

Now then, if you want to find what the sag would be at some different temperature under the stringing condition of load,—that is, no load except the weight of the wire itself,—you follow the stretch curve to the axis.

The stretch curves are plotted for definite intervals of temperature, say, ten degrees. If the coefficient of expansion is a constant, it doesn't matter what the temperature is; one can shift the temperature scale to suit. Say you have taken the loaded condition at zero degrees and the stringing temperature at 60 deg.; you follow the axis for 60 deg. and return on another constant-temperature line to the load represented by, say, the weight of the conductor only. This point gives the stress and the sag for your stringing condition.

That gives a very rapid method of computing sags without any successive approximations and will fit any temperature and any loading. The only requirement necessary is that you have your chart to begin with.

If one has a great deal of this to do, it is worth while to compute the chart and have it on hand. Of course if one has only one problem to work out, it is easier to use the formulas. The author mentions a paper by Martin presented before the Engineers Society of Western Pennsylvania in which he has worked out some tables giving the catenary functions. They are very useful in a single case; in fact, we have sometimes found them preferable even in doing a lot of such work, since working over curves like these and attempting to interpolate between the drawn curves to obtain accurate results requires very close attention and careful work and it becomes very tiresome and exhausting if kept up for any length of time. On that score, it is easier to do computing, if you can do it, in a mechanical way with computing machines, as it takes a great deal less mental effort and less eye work.

I might say also that we have worked these charts out with the principal materials used, such as copper, aluminum and steel. In working them out, we used formulas somewhat similar to these in the paper, expressing the catenary functions in series.

H. B. Dwight: Has the work with curves for sag calculations, as described, been done for the case of supports at unequal heights or for cases of supports at equal heights only?

Mr. Lloyd: What I said applied to equal heights only.

H. B. Dwight: Is there any work on the other as yet?

Mr. Lloyd: No, not to work it out in the same way, except that with unequal heights, in considering the curve of the wire extended, you have always equivalent cases of equal heights of a span of greater length, of which your actual span is merely a portion; and you can always work it out in that way.

E. V. Pannell: The high degree of accuracy being striven for in transmission line-calculations is most noteworthy, but the question is whether the mathematicians have not gone a long way ahead of those responsible for testing the fundamental properties of material? While sag and tension calculations are being made to four, five, or even six significant figures, it must be admitted that knowledge of the physical properties of the wire does not come anywhere near this degree of exactitude.

The fundamental property in all calculations of wire extension is the modulus of elasticity. For copper wire, this is variously reported as from 16,000,000 to 18,000,000 lb. per sq. in. Here is evidently a difficulty and a possible error of 12½ per cent. In the case of aluminum, various investigators have reported a modulus of 9,000,000 and 9,500,000 and 10,000,000 lb. per sq. in., involving a possibility of error almost as great as for copper.

The properties of the wire when stranded into cables of various lengths of lay and characteristics become still more involved and except in the case of certain German laboratories, I know of no thorough tests having been made on a scientific basis by which attempt could be made to establish these properties.

It would seem as if the great degree of accuracy possible in a mathematical manipulation described by Dr. Dwight and other investigators is very nearly useless until the physical constants of wire and cable are more soundly established.

H. B. Dwight: The discussion by Mr. Pannell brings out a matter of considerable engineering importance. The physical characteristics of stranded cables, such as modulus of elasticity and temperature coefficient of expansion, are not known with exactness for standard conductors. Accordingly, further tests should be made to determine the average values of these constants and their usual amount of variation.

It is not necessarily obvious at first sight what is the effect of a certain percentage change in one of the constants, and it would appear to be a good engineering procedure to repeat a sag calculation using maximum and minimum values of a constant, so as to find what effect the variation has on the engineering decisions which depend on the calculation. If this were done for the two constants mentioned above, important changes in the results would be obtained.

In general, one should not write the values of engineering quantities with a precision greater by more than one significant figure than the precision of the measurements on which the quantities depend. Exceptions to this rule, however, are sometimes justified. For instance, one is justified in assuming the length of a span to be exact, as 800.00 feet. The sag calculation really deals with small changes in length. If the calculation should be repeated for a span of 801.00 feet the difference would be minute. If the length of span is considered to change after the application of a load, as by deflection of the towers, this should be taken up in a separate calculation.

When one wishes to compare two methods of calculation, one is justified in assuming for that purpose that all the constants are known with precision. The results are useful for the purpose intended.

Even where a constant is not definitely known, it is good engineering practise to adopt a standard value so as to design all the spans of a transmission line to have the same factor of safety rather than by irregular designing to have one span weaker than the others. Thus, a standard value of ice load or wind load is adopted even though the probable maximum value is uncertain. So also for the sake of uniform design of all the spans, it is proper to take a standard or average value of modulus of elasticity. The effect of possible variations in this constant can be made the subject of a separate investigation, as previously mentioned.

Where average values have been taken for several quantities, their deviations will probably cancel out to some extent in their effect on the final result, and so it is justifiable to carry out the computations based on the average values, with a moderate degree of precision.

The above mentioned reasons for making precise computations do not justify adding more than about one or two significant figures except in the case of the length of the span, or in the case of comparing two mathematical methods. In Table I of the paper by Dr. G. S. Smith[3], the modulus of elasticity is given as 29,000,000; that is, to two significant figures. This is multiplied by some quantities depending upon the section of the cable, and the result is given in section (13) of Table I as 3,153,306,102; that is, to 10 significant figures. This is due ap-

3. Transactions A. I. E. E., 1925, p. 938.

parently to the plan of writing the result of all multiplications with as many significant figures as a calculating machine will give, but when this is done, it does not seem possible to tell what figures have use and meaning and what have no meaning. Such a procedure masks the precision of the different parts of the calculation, and gives the impression that no attention is being paid to the relative precision of the calculation. It would seem better to give only such figures as are intended to be used.

The use of charts has a place in the calculation of sags, as described by Dr. M. G. Lloyd or as described in a number of A. I. E. E. papers. A chart method may give a sufficient degree of precision for a certain class of work, but this should be carefully determined. It should be remembered that a reading taken from a curve is correct to a certain number of significant figures, and the final result cannot be accurate to a greater degree than that determined by the curve reading. In sag calculations, especially where temperatures are involved, the discrepancies resulting from taking readings on curves may be greater than are desirable in designing.

The discrepancy between the values of deflections obtained in my paper and in that of reference (8) is due to the fact that two different catenaries have been assumed in the two papers, for the case of unequal supports with wind load. While the deflections are different, since they are measured to different lines, the difference in the stresses obtained by the two calculations is not appreciable for practical spans.

NOTES ON THE VIBRATION OF TRANSMISSION-LINE CONDUCTORS[1]

(VARNEY)

NIAGARA FALLS, N. Y., MAY 28, 1926

A. E. Knowlton: The principle of aerodynamics which Mr. Varney cites to account for the vibration of the transmission-line conductors is undoubtedly the same one which is found applied in the propulsion of Dr. Floettner's rotorship. The one difference is that he rotates the rotor and keeps the pressure always in one direction. That is not, of course, the case with the line conductors. The instability there results in alternation of the pressure and consequent vibration of the conductor.

Another and more important difference is that Dr. Floettner has made a useful application of it and one can't say as much in the case of the line conductors. The fact is that we get two distinct results; one useful and the other deleterious.

A committee of operating engineers is attempting to assemble the facts that have been observed and perhaps have been recorded in connection with this phenomenon, so that we can draw conclusions not merely as to the rigidity of the theory as Mr. Varney has set it up, but also upon the efficacy of certain preventive measures.

Theodore Varney: In closing, I think Prof. Knowlton's comment regarding Dr. Floettner's rotorship is appropriate. While Dr. Floettner turns the eddy effect of the wind to good account, the same influence accomplishes no good result in a transmission line conductor. It is not correct to say, however, that this effect is always deleterious in the latter case because cases are on record where vibration has been going for over ten years without interference in any respect to the continuous and successful operation of the line.

As the speaker views the matter, destructive effects will result from vibration only when the direct stress in the conductor increased by the stress due to vibration exceeds the endurance limit of the material of the conductor.

This is a complex problem, but it appears that the stress due to vibration is directly proportional to the stored energy in one half of each vibrating loop and inversely proportional to the distance over which that energy is dissipated. This energy is expressed by the mass of the half loop, the square of the amplitude and the square of the frequency of vibration. This energy passes back and forth freely between loops in the span away from the supports. At the supports there is an inevitable bump and increase of stress, which can be greatly reduced by care in clamp design.

The most beneficial remedy is to reduce the amplitude of vibration by dampers.

1. A. I. E. E. JOURNAL, October 1926, p. 953.

RECTIFIER VOLTAGE CONTROL[1]

(PRINCE)

NIAGARA FALLS, NEW YORK, MAY 27, 1926

R. H. Wheeler: The paper by Mr. Prince is a very interesting discussion of the potential possibilities of the use of the interphase transformer.

The interphase transformer has been utilized for a long time by Brown Boveri & Co., Ltd., and is incorporated in the circuit diagrams which the American Brown Boveri Electric Corporation has put forth in some of its proposals. We have not used the saturated-core type, however, for it long ago was demonstrated by many installations that the close regulation of the modern sets was sufficiently close for all traction purposes and very few industrial applications require the complications of the saturated interphase transformer.

Extended experience has also proved of late years that the compound rotary converter has not taken the position that it enjoyed some years ago when over-compounding was thought necessary. Wherever compounding is used of late it has been entirely of the flat compound type. To our knowledge, however, the shunt rotary converter has had a much greater application and appears to satisfy regulation and voltage conditions in all usual operations. To meet the flat compound or the over-compounded rotary converter, there has been introduced into the mercury-arc rectifier installation circuits an induction regulator which quickly compensates for the drooping characteristic of the rectifier and permits it to parallel at all loads with compound rotary converters.

There have been a number of schemes utilizing a variable-reactance core in the interphase transformer. The d-c., saturated core described by Mr. Prince has been utilized in a number of installations some years ago, but has since been abandoned because of a number of factors which limited the degree of compounding demanded by commercial practise. We have found that the rising voltage characteristic is not sought by purchasers of such conversion machinery.

The paper by Mr. Prince points out that the regulation is largely a function of the variation in load as it increases and decreases. The scheme as offered does not permit an independent voltage control. We have found that there are possibilities of utilizing shunt connections which will permit the movement of the voltage curves vertically upward or downward, at the same time obtaining the benefit of the control Mr. Prince has described. The Brown Boveri Review of 1919, Nos. 7, 8 and 9, describes such an installation and discusses the possibility of shifting the load by voltage control of the rectifier where a rectifier and rotary converter are operating in parallel.

During the extended development of the mercury-arc rectifier in large power sizes, as carried on by the Brown Boveri & Co. Ltd. of Switzerland, various schemes have been developed and patented, which permit of a flexible voltage control. These forms of control, however, include complications of circuits which demand additional reactance coils and machinery, and are not as commercially practicable as the circuits now offered, which provide for usual shunt characteristics. There is always available the induction regulator, transformer, tap changer, or similar device for changing the voltage of the sets.

The mercury-arc rectifier has been installed in heavy electric traction service at varying voltages up to 4000 volts, d-c. The limit of the phenomena of conversion by the mercury-arc rectifier

1. A. I. E. E. JOURNAL, July, 1926, p. 630.

does not seem to have been approached at the highest commercial d-c. voltages in operation today. The rectifier is causing a great deal of study to be made of its possibilities by engineers interested in the electrification of steam railroads, since the weights and dimensions are at a minimum not heretofore reached per kilowatt of substation output. No overhead cranes, heavy wall construction or heavy machine foundations are required in such substations. The operation of putting the machine in service or taking it out of service is no more complicated than throwing on the bank of transformers which serve the rectifiers, thus permitting the substation employee to be easily trained and of a type not essentially classed as "highly skilled." I can clearly visualize the use of the rectifier being established along the right-of-way of a steam railroad at much more frequent intervals than the rotating machinery type of substation providing much closer d-c. trolley regulation and obtaining alternating current from any commercial source of any commercial frequency, thus obviating the use of railroad-owned power stations and transmission systems.

It is interesting to note the control of the voltage and current curves as described in the paper by Mr. Prince. He sets forth the current characteristics in a very detailed fashion and we think that if it is possible to apply these schemes of voltage control to the twelve-phase rectifier, a very satisfactory current wave form will result.

Frequently we have been asked "What about radio interference?" because of the undulating character of the current wave form. Exhaustive tests were made by the largest utility company in the middle west, using very sensitive radio receivers which were moved about the substation, and placed in all positions, to determine the extent of interference with radio reception. The results of this test proved definitely that there is no interference caused by the wave form emanating from the rectifier and through the circuits it feeds. We believe this test is of interest, as the wave form of the theoretical circuit might cause an apprehension upon the part of some engineers if the practical test had not been made. Furthermore, full appreciation had not been given to the fact that the superimposition of many phases of rectification causes practically a flat wave rather than a sharply undulating wave.

Otto Naef: I think Mr. Wheeler is right when he says that in Europe not much use has been found for the interphase transformer with d-c. magnetization. The method proved successful from the point of view of voltage regulation, but this asset was not considered important enough to set aside the disadvantage of higher cost, lower efficiency and power factor in a plant thus equipped. Besides, there has been a marked tendency in Europe in the last few years to eliminate, so far as possible, any complicated features.

I may mention here that instead of using a saturated interphase transformer, saturated transformers or choke coils in the anode circuits may be used with equal success. In addition to, or instead of, a series winding, a d-c. shunt winding may be put on the core, which, if excited from the d-c. mains, makes it possible to raise and lower the characteristic of the rectifier in much the same way as in an ordinary shunt-wound, d-c. machine.

Mr. Prince's curve shows a very steep rise in the voltage at low loads, which is a characteristic feature of the interphase transformer. It can be avoided by using a booster transformer instead of the interphase transformer. It may be excited from the low side of the rectifier transformer through a reactance coil, the inductance of which is varied by the application of d-c. magnetization. In this way it is possible to vary the boost and thereby obtain compounding of the d-c. voltage without getting that first kick.

F. A. Fardon: Mr. Prince has removed one of the serious disadvantages of mercury-arc rectifiers when applied to railway service. A considerable proportion of the rectifier applications will be additions to systems where revolving apparatus having very definite characteristics is already in use. It is hardly conceivable that the characteristics of an existing system would be changed to permit the application of rectifiers with naturally drooping characteristics. On many occasions, it is necessary to install an additional unit in an existing station containing converters, and a rectifier with drooping characteristics would divide loads properly with the existing units at *only one* point. Beyond that, the converter would have a tendency to take too great a share of the load and at low loads the rectifier would cause reverse current to flow through the converter, which would at least force the converter off the bus and possibly cause other difficulties. This condition is analogous to attempting to operate a shunt-wound and a compound machine on the same bus, which we all realize is a very unsatisfactory arrangement.

It has been proposed that the rectifier be operated with converters where the regulation of the converter is poorer than that of the rectifier. This is a very unusual condition, and I am not familiar with any place where this condition exists.

With the method of compounding suggested by Mr. Prince, the interphase transformer may be arranged so that the saturating winding may be equalized with the series field of the converter, insuring load division at all points.

Compounding is desirable from an economic standpoint, as none of the features considered desirable in a rectifier are impaired and holding practically flat voltage at the substation is a condition which requires a minimum amount of feeder copper. This is applicable to approximately 90 per cent of the railway substations in this country.

A rectifier without compounding is comparable to a shunt-wound converter having about the same regulation, whereas, with the compounding feature, the regulation is practically the same as that of a compound-wound converter. Other methods, such as tap changing or use of an induction regulator, while applicable possibly to an isolated station, are objectionable on account of external devices requiring maintenance, and the fact that no induction regulator is fast enough to follow load swings on the average railway substation. If possible to build a regulator of this sensitivity, the maintenance would necessarily be high, as the unit would be in practically continuous operation.

The method of regulation offered by Mr. Prince is as simple as the series field on a converter. It will find large application and may be considered one of the most valuable additions to information on rectifier circuits made in recent years.

E. B. Shand: I more or less agree with Mr. Wheeler that the shunt-wound converter is becoming more popular now for traction and the value of the over-compounding or flat compounding is not as great as it used to be.

There is one point to be made, however. It will be noticed that with the core unsaturated you get the effect of the ordinary balance coil and that the anode current flows for one-third of a cycle, but that with the balance coil saturated it flows for only one-sixth of a cycle. That means the transformer will have to be about 25 per cent larger; so it will be economically at a disadvantage.

D. C. Prince: In the discussion of this paper, three questions have been raised: 1. Can the method be employed to give voltage control independent of line-current variations? 2. Is excessive transformer secondary heating introduced by the operation of compounding? 3. Will its popularity be reduced by the trend toward substation layouts which limit the load on one substation by dropping its voltage?

In answer to the first question, I should say that the problem of saturating the interphase transformer from a separate source is simpler than that of obtaining the correct characteristics by self saturation. If the latter problem is solved, the former follows automatically.

As a rectifier is loaded, the current waves in the several secondary windings spread out so that their utility factors improve. In a flat compound rectifier, the tendency of the compounding to make the utility factor worse is offset by the normal tendency of this factor to improve with load. The light-load utility

factors are three-phase 0.68, six-phase 0.55. The six-phase, short-circuit, secondary utility factor is 0.75 so that the transformer would not be expected to require materially greater secondary copper on account of compounding. Utility factor is defined as the ratio of no-load rectified voltage times rectified current to alternating sine-wave kv-a. for the same root-mean-square heating.

A very desirable thing about the compound characteristic is that by the use of high-reactance transformers it can be taken advantage of to hold substantially constant voltage to full load and yet with overloads the voltage breaks down more rapidly than that of a shunt machine so that the unit will shift its load to other substations. Since the rectifier cannot fall out of step, a generously designed set might be made to stand short circuit for a brief period without being tripped free of the lines.

LIGHTNING AND OTHER EXPERIENCES WITH 132-KV. STEEL TOWER TRANSMISSION LINES[1]

(Sindeband and Sporn)

Niagara Falls, N. Y., May 28, 1926

F. W. Peek: Messrs. Sindeband and Sporn's paper gives some very good data on practical lines in confirmation of experimental and theoretical work which I have been doing on this subject.

I have been very much interested as to the voltages that may occur on transmission lines due to lightning, the nature of these voltages and the ability of the insulation to withstand them. The spark-over voltage of an insulator is quite different for lightning voltages and 60-cycle voltages. Fortunately the lightning spark-over voltage is much higher than the 60-cycle, spark-over voltage and is not affected by dirt, rain, water or other foreign material on the insulator. About what voltages should be expected on a transmission line due to lightning and what is the insulator strength? If these factors are known it is easy to predict whether or not trouble is likely on any line. My investigation made partly in the field and partly in the laboratory on models with the lightning generator shows that the maximum voltage that can occur on a transmission line depends upon the height of the conductor above ground. In fact, the lightning voltage above ground on a line is equal to a constant times the height of the line in feet. Thus:

$$V = g\,\alpha\,H = G\,H$$

where H is the height of the line in feet, g is the gradient in volts per foot at the instant before discharge while α depends upon the rate of discharge of the cloud and the size of the cloud. It approaches unity for a large rapidly discharging cloud. The highest value of g is 100,000 volts per foot. The maximum voltage that can occur on a conductor insulated above ground is thus 100,000 times the height of the line in feet. For theoretical reasons it is easy to see that that value will apply only in case of a direct stroke. Since direct strokes are not a very common occurrence, data obtained on actual lines during flashover are of greater interest. Values of the apparent gradient of from 20,000 to 30,000 are quite common, while values of 50,000 have been observed.

The practical lesson that can be drawn from this formula, I think, is best illustrated by an example. I shall take height above ground and conductor separation approximately equal to Mr. Sindeband's case. Assume 40, 50 and 60 ft. as the average height of the conductors above ground. Assume further that the storm is about a quarter of a mile away and G is 25,000. The voltage on the top conductor is then $G\,H$ = 1,500,000 volts. On the next conductor down it is 1,250,000 volts and on the bottom conductor just 1,000,000 volts. If a 10-unit string of insulators is used the lightning spark-over voltage is 1,400,000.

For this particular storm and this particular insulator and tower the top insulator would spark over, while the middle and bottom ones would not. With a more severe storm the top and middle would spark over. At G = 35,000 all three insulators would spark over.

In confirmation, Mr. Sindeband's data show that most trouble occurs on the top conductor; next on the top and middle and finally on all three.

Incidentally, such data offer a method of measuring these voltages. If the top insulator sparks over and not the other two the voltage is known within the difference between 60 and 50 or about 20 per cent. From the voltage and height of conductor the gradient is known. If the top and middle insulators spark over, a similar measurement is made.

From the standpoint of lightning alone it is undesirable to have a high tower.

If the above conductors were placed in a horizontal plane 40 ft. high, the voltage above ground for this particular storm would be 1,000,000. There would be no potential difference between conductors as in the case of the vertical arrangement. For the storm in question there would be no spark-overs.

How about the ground wire? Theoretically and also from studies made on models in the laboratory a single ground wire approximately cuts the lightning voltages in half if it is installed under favorable conditions. If it is assumed that the above factor holds in practise it is equivalent, as far as lightning is concerned, to doubling the insulation of the line, but with one very decided advantage. Doubling the line insulation doubles the voltage on the apparatus while the ground wire cuts it in half. If it functions properly, there is thus a double gain in using the ground wire.

Whether or not there is trouble on a line from lightning is a matter of the height of the tower and the insulation and is entirely independent of the line voltage except as it governs the number of insulators and the height of the tower. Since high-voltage lines are better insulated, less trouble should be expected.

I wish to say a few words on Mr. Sindeband's work and experience. Arc-overs have been experienced first principally on the top insulator, then on the top and middle, and next on all three. Instead of putting a great many more insulator units on the line, Mr. Sindeband has installed ground wires hoping that the ground wires will materially reduce the voltages and thus reduce the trouble. In addition, he has added the device at the end of the insulator string, shown in Fig. 18. This device is known as a grading ring or shield and was first developed for 220,000-volt lines in California. Its object is, primarily, to make the voltage distribute evenly over the string and make each insulator take its share of the voltage. In this part of the country, where there are heavy lightning voltages, it causes them to divide evenly over the string and makes each insulator take its share of the voltage. However, another very important function of a device of this kind is in case of an arc-over. It seems impracticable to make most low and moderate voltage lines absolutely lightning-proof, though it can be done if the cost is justified by making the tower low, using a number of ground wires and extra insulators. It is very important, therefore, to have some device that will cause the arc to clear the string and prevent burning and cracking of the insulators until the arc is suppressed by sectionalizing or otherwise. A horn gap might be used for this purpose. Studies we have made with the horn, however, show that it is very difficult to make it effective. The reason is quite obvious. It is this: With the horn there is no appreciable grading; about 25 to 30 per cent of the voltage is on the line unit. The sudden application of a lightning voltage causes the bottom unit to arc over, then the next and so on up the string. A complete cascade results. Even though a horn is adjusted at 60 cycles to clear very well it does not clear when the arc is started by lightning unless the separation is greatly reduced. We have not found this to be the case with the ring; it causes an even distribution at the start and there is no tendency for the initial arc to cascade.

1. A. I. E. E. Journal, July, 1926, p. 641.

It clears the string and the 60-cycle arc follows the path of the lightning arc. If the relays operate quickly there is no damage to the insulators.

There have been very few actual operating data on the value of the ground wire. However, recent work indicates that the ground wire functions as the laboratory experience and the theoretical work shows. You will observe in Messrs. Sindeband and Sporn's study, as would be expected, that most trouble occurred on the top conductor. In a similar tower equipped with a ground wire there would be practically the same voltage on all conductors. Data on a line with a ground wire should, therefore, show a more even distribution of trouble. That is exactly what has been found.

L. E. Imlay: We have one important tower line supporting six circuits on which we have five grounded guard wires. We have had no lightning disturbances on this line except in two instances when the lightning came in from connecting lines having two ground wires. From our experience we believe that five grounded wires on the top of these towers give practically complete protection.

L. C. Nicholson: The Niagara, Lockport & Ontario Power Company operates a system of some 2000 circuit miles, mostly at 60,000 volts with some 110,000-volt circuits. The practise of the company is to use ground wires. We have had experience both with and without ground wires. Our experience without them was very undesirable.

The construction that has gone up in the last ten years is of the A-frame suspension-structure type with square dead-end towers using two ground wires, the ground wires being used not only for electrical purposes but also, for mechanical reasons, to support the A-frame structures. The ground wires used are substantial in size and well grounded and have given little if any trouble.

While we can't say that flashover from lightning on lines equipped with ground wires is nil, yet it doesn't amount to a great deal. I think it would average, in rough figures, one flashover per summer per hundred miles on a double-circuit line. From five to seven insulator units are used on 66,000-volt lines. The 110,000-volt system is not very extensive and has not been in service very long so I am unable to give any conclusive figures on that.

The burning of conductors sufficiently to cause them to drop is almost unknown. I attribute this to the fact that the arc does not remain in one position long enough to burn the conductor in two or seriously damage it. I believe there have been occasions when small conductors dropped within a time period after the occurance, but the matter of burning of conductors is not a serious one.

Insulators do not puncture. This is another great measure of progress which has been made in the last 10 or 15 years. When we first started operating that was our main trouble. They now occasionally flashover, but are seldom destroyed or disabled.

E. S. Healy: There is one important phase of flashover trouble that should not be lost sight of. Under all reasonably possible wind conditions, adequate clearance must be maintained on every tower in a transmission line.

In rolling country, it is very easy to encounter special conditions that give short clearances. Any special construction requires a careful study.

Of course, any difficulties caused by insufficient clearance must be eliminated before a study of lightning effect can be made. In the two cases of flashover troubles that I have been entirely familiar with, inadequate clearance was at least a contributory cause. One of these was a tree which had probably caused occasional trouble for nearly two years before it was discovered. Aluminum and small copper conductors will blow out and carry the insulator into seemingly impossible positions.

S. S. Hertz: An entirely new engineering contribution in Institute papers has been made by the authors, and that is the analysis and publication of their *mechanical* experiences with overhead ground wires. Their contribution of field experience in its *electrical* aspect is also especially valuable, adding to the fund of data in several previous Institute papers on the electrical aspects of the overhead ground wire, such as those contributed by Dr. Steinmetz, Mr. Peek, Mr. Creighton and others. At the Midwinter Convention of 1922, Dr. Steinmetz strongly emphasized the electrical protective value of the overhead ground wire for certain types of lines, giving his preference to the overhead ground wire over the lightning arrester, principally because the advantage of the ground wire is that its function is preventive while that of the lightning arrester is merely curative.

Mechanically, the overhead ground wire has gradually undergone an evolution which is of value to note here. Starting years ago with barbed-wire and almost no standards of construction, the overhead ground wires have been gradually improved until today it is generally agreed that the overhead ground wire circuit should enjoy the benefits of the same standards of construction as are used in designing the power conductors. That is exactly what the authors have done in the lines described. Operating difficulties and troubles from mechanical failures of overhead ground wires which, on few properties, have prejudiced the use of any overhead ground wire, can be fully solved by improving construction standards. The overhead ground wire, if used at all, should rigidly adhere to at least the same standards of material and construction as used in designing the power conductors with which they are to be placed.

The following improvements in construction standards are the ones which appear most needed to bring the trend of overhead ground wire design to par with the general design of power conductors. These standards have been employed on several of the recently constructed transmission lines:

a. Use of suspension clamps and strain clamps for the ground wire of the same general design as used for the power conductors.

b. Placing slightly less sag in the ground wire than in the power conductors (in sleet districts). This is advisable to provide ample separation when the ground wire is carrying sleet while the power conductors have shed their sleet load.

c. Use of non-rusting wires, so that the natural life of the ground wire will be at least that of the power conductors.

d. Assigning a slightly greater factor of safety to the ground wire than is given to the power conductors. For example, where the power conductors are designed with a safety factor of 2, it may be advisable to have a factor of safety of about 2,25 in the ground wire. In emergencies affecting the supporting structures, the ground wire would have to bear the greater part of the strain and in any occurrence of trouble it is good practise to have the ground wire safer than the power conductors.

H. B. Vincent: I'd like to ask Mr. Sindeband two questions: Has he determined the most efficient setting of the arcing ring with respect to the wet flashover of the string? In other words, what percentage of the wet flashover of the insulators is the wet flashover of the arcing ring? If so, at what ohmage water is the wet string figured?

Has he any record of troubles which actually occurred during rain storms?

Is the flashover shown in Fig. 18 a wet or a dry flashover?

N. J. Neall: Something that has been said in the discussion prompts me to mention a feature of lightning-arrester performance that has been observed during the last year in connection with some comparative tests of lightning arresters on an 11,000-volt system where a number of circuits are carried in a parallel horizontal plane arrangement to a given substation over an H-frame construction. It was found that the arresters attached to the upper transmission wires, particularly those just under the overhead ground wires, were the principal ones to discharge and the inference, pending further information, is that we have a sort of succession of protective zones beginning with the over-

head ground wire and then downward from conductor plane to conductor plane.

A. O. Austin: With the rapid changes in transmission work, there is a tendency to make an installation which is copied in many instances before operating records are available which will show up difficulties or advisable improvements or modifications. Hundreds and even thousands of miles are put in before any real operating experience can be obtained. This time lag is unfortunate and leads to a serious situation because line trouble of any description affects not only the operation and subsequent expenditures but financing as well.

In 1916 I presented a paper before the Toronto Branch calling attention to the dangers which were likely to occur with an increase in the size of the system, unless the factors of safety were materially improved. The discussion today brings this out clearly, hence the extended interconnection of large networks should be given careful attention as the increased trouble frequently more than offsets any economic advantage. The splitting up of systems, during storm periods or where the margin of safety is rather small or the circuit breakers likely to blow up, should also have more attention. A short circuit on the line today is far more serious than it was a few years ago owing to the fact that conductors are generally larger and the amount of current fed into a short circuit will create far more damage, not only to the line but to the possible connected apparatus. The time of clearing a short circuit also tends to increase with the size of the system in order to obtain selective relay operation.

Today plants are penalized for poor power factor, which results in loading the motors more heavily so that a drop in voltage frequently allows much apparatus to drop out of step. This causes heavy losses in some plants and inconvenience in all, warranting considerable expense where even momentary drops in voltage or bumps on the system can be eliminated.

In addition to the increase in number and seriousness of transmission interruptions, the cost of transmission lines is becoming more of a factor in the total cost of power. Additional parallel circuits are required to offset interruptions where lines are subject to flashover. The additional cost must be incurred whether or not the line can be cleared with a relay and circuit breaker. On some of the large systems considerable time is required following what would normally be considered a momentary interruption on a small system, before the line can be put back into service. There can be little question but that the success of future transmission systems demands that flashovers be eliminated as any other method is too costly and uncertain of results.

The whole subject needs the most careful consideration. If we apply common sense and carry the analysis far enough it will be found that there is general agreement as to the fundamentals necessary for the construction and operation of a transmission system. Above all we should not expect results which are not justified either partially or wholly by consideration of fundamentals.

The ground wire is a good example in point. A poorly installed ground wire may cause much mechanical trouble and while it may be of some benefit in reducing induced voltage or in absorbing a surge, the trouble which it causes may more than offset any advantage. Where the ground wire is installed on a wood pole it may so reduce the insulation that flashovers will result even though the maximum voltage may be reduced. While the shattering or burning of poles may be prevented, the increase in bird troubles and the elimination of the insulation furnished by the wood may more than offset any advantage in the use of a ground wire in this case.

Where a ground wire is installed on a steel structure the situation is somewhat different since there is no insulation in the structure to cut out. If the ground wire has good mechanical reliability it will, of course, reduce the maximum voltage tending to flash the line and, in general, conditions will be improved. There are some cases where the ground resistance is exceedingly high and if this resistance is materially reduced by the use of a ground wire, short circuits from lightning and birds will be increased.

An analysis of the field conditions, as well as tests in the laboratory, shows that a very great improvement may be expected from the complete impregnation of poles which will eliminate a low-resistance core. This low-resistance core tends to cause the pole to be shattered under lightning. This shattering can be eliminated only by increasing its resistance or by providing a shunt path. The former may prove most economical for new lines whereas the latter may be necessary for lines already installed. A down lead or lightning rod on the side, while saving the pole, tends to eliminate the insulation unless the ground resistance is high. In some cases the use of a gap in this circuit may be used to advantage in increasing the effective insulation for a surge or to prevent bird or squirrel trouble.

In the construction of a new system better operating conditions will be obtained if the cost of a good ground wire is used to provide more insulation and tower clearance or a more favorable electrostatic field around the conductor or live parts in the vicinity of the tower.

The old method of using a compass in tower design to determine clearance should be abandoned, as two towers having the same clearance may set up widely different electrostatic-field conditions so that one tower may have many flashovers while another tower having the same clearance may have few, if any, under the same conditions.

The ground wire is an old device and outside of improving its mechanical reliability, its application has developed little, if any, over a number of years. Practically the only improvement has been the limited use of the insulated ground wire which has given very good results.

It would seem that an improved application of the ground wire is very necessary and desirable if we wish to improve its effectiveness, and it is predicted that a great increase in its efficiency will be possible in a short time.

Bird trouble is a serious problem on some systems but it may be readily eliminated if wood poles can be kept from shattering or burning. This subject is receiving careful attention and reports from the field as well as experimental results would indicate that material improvements are possible in this direction. I am certainly not against the use of a ground wire. If, however, we find an improved method of using it or increasing its efficiency we may do much to reduce trouble and the cost of transmission lines.

The discussion today apparently leans toward the low structure. While I do not believe that this is essential where the necessary factor of safety is provided to offset the greater voltage induced on the line, it has certain advantages. The low structure means more supports and more insulators. More supports will permit the use of lighter insulators with much longer economic life which more than offsets the increased quantity. Where the low structure with its lighter mechanical loads is used it is possible to provide towers or structures which will set up a more favorable electrostatic field and thereby provide a higher flashover voltage between conductor and ground for a given length of insulator.

Owing to the fact that the electrical problems in preventing flashover on the transmission line are not so generally understood as the mechanical problems, there is a tendency to develop the mechanical end of the structures at the expense of the electrical performance of the line.

Unless the ground wire is so situated that an effective shielding exists, the upper conductor receives the greatest stress. While this is generally recognized there are few lines which provide more clearance and insulation for this conductor. On the contrary, the upper conductor usually has the lowest flashover stress for operating conditions. This results in much more

trouble than would be the case were the insulation and clearance graded in proportion to the stress imposed, whether this be the top conductor or the lower conductor. If the location of the ground wire reduces the stress on the top conductors so that the lower conductors have a higher maximum induced voltage we should provide greater insulation and clearance for the lower conductors. An arc from conductor or live surface to a tower member or ground is bound to be destructive if there is any appreciable power connected to the system and the successful line of the future will be designed to prevent arcs to ground rather than minimize their damage after they form.

In some cases it is necessary to minimize the destructive effect of flashovers, as it may not be possible to eliminate flashovers without incurring a prohibitive cost. The success, however, of some rather low-cost lines leads us to believe that a great improvement may be possible through a proper consideration of tower design and clearance and a better realization and use of the ground wire itself.

While the ground wire has been improved mechanically, its electrical efficiency has not been improved over the earlier installations. In some cases I have used a ground wire effectively to eliminate troubles which were very serious. In others trouble has been materially reduced by the removal of the ground wire. Hence, its economic importance depends upon the particular application.

More attention must be given to the tower as many of the newer and more expensive lines have made a poorer electrical showing than some of the earlier and cheaper lines. This is natural in a way as building costs have gone up tremendously and the tendency has been to offset the increased cost by building towers of smaller clearance or greater mechanical strength to handle the larger conductors. Since fixed charges form an appreciable part of the cost of power on many systems we are likely to use designs which cut the factor of safety, causing increased troubles, particularly where there is no precedent upon which to draw. There is a tendency to use a relatively shorter arm with the increasing size of conductor. This, together with the high braces and wide face of the tower in the direction of the line, while economical from the tower standpoint, makes the problem of preventing flashovers exceedingly difficult. Tower clearances in the past have been laid out by means of a compass rather than by studying the electrical field set up.

Much time and thought has been given to this subject over a period of years and I feel that within the next year a material improvement will result in the construction of transmission lines as the relative performance of different constructions can be determined experimentally to a very large extent and it is gratifying to know that results in the field apparently conform to tests in the laboratory.

It is exceedingly difficult to improve the standard of an existing system although it is evident that if a system having a low standard of operation is connected to another portion having a high standard, both of them will operate on the lower standard. Usually anything within reason which will raise the standard of the old system is justifiable and much time has been spent upon this problem.

It would seem that a new system should go in with ample clearance. I should rather see a new line go in with ample clearance and no ground wire rather than have the system installed with a smaller clearance and an expensive ground wire, as the latter can always be installed later whereas increasing the clearance after installation is a difficult and costly proceeding. Owing to the more severe conditions which may arise through interconnection, a ground wire which was unnecessary on the smaller system may prove advisable and can be installed at little additional expense over that necessary were it incorporated in the first installation.

As systems grow the demand and value of greater reliability increases and if this is hampered by too small a clearance or poor field conditions at the tower, the problem of providing greater reliability will be exceedingly difficult. While certain fundamentals are recognized clearly in the laboratory, it seems to me more difficult to recognize the application of the same fundamentals in preventing flashover on the transmission line.

On the transmission line the problem is to prevent an electrical discharge between the conductor or live part and the tower and support. The problem is to prevent the break-down of the air; hence, anything which will affect the maximum stress on surfaces which will normally discharge will have an effect upon the flashover voltage. It is obvious that the density of the field surrounding a conductor or a live part may necessarily vary greatly for a given clearance with the wide range in tower designs so that general statements based upon a specific instance may be very misleading. In most lines the discharge starts probably from the conductor or live part while in others there is reason to believe that the discharge actually starts from the tower or ground side owing to the fact that the greater density in the air is produced on this side of the gap. Where the latter condition exists, increasing the size of the charged surface on the conductor will necessarily tend to lower the flashover voltage and increase troubles, although in other cases this might be a very material advantage. While this is too large a subject to go into detail, a consideration of the conditions between electrodes will illustrate the problem fairly well and not only show the inconsistencies but, what is even more important, a means for increasing the flashover voltage for a given clearance. While this is fairly simple between ordinary electrodes, the problem is more

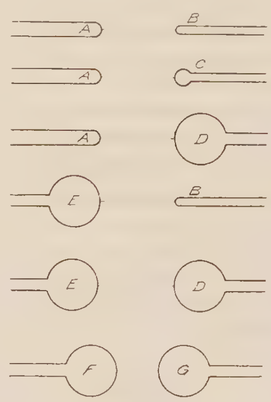

Fig. 1

difficult in service owing to the effect of rain and mechanical considerations.

Referring to Fig. 1, if we have a grounded electrode, A, and a live part, B, with a given distance between them, it is comparatively easy to determine their flashover voltage for conditions which are likely to exist on the line. If we maintain the same clearance between electrodes but use electrode C in place of B, the flashover voltage under the same conditions will be increased, particularly if we pay no attention to polarity. If, on the other hand, A remains the same and we replace the electrode C by electrode D, the flashover voltage will be reduced and may be even lower than that for A and B, owing to the greater concentration of stress in the air around electrode A. If we replace electrode A by electrode E on the ground side in combination A-B as in E-B, the flashover voltage may still be the same as in the previous case A-D, but will be lower than for A-B. If E represents the electrode on the ground side, and D on the line side, the flashover voltage will be materially increased over any of the previous cases. There can be no question about this and it only remains to make the application to the transmission line in order to improve the flashover voltage materially with the

resulting decrease in the number of flashovers. Up to the present time, there has been no line application which corresponds to the gap *E-D*, the applications being more on the basis of *A-C* which must necessarily have limitations compared to the possibilities of the gap *E-D*. There is one other case which it is well to consider, and that is the condition where we have a gap similar to *F-G*. In this case, while the electrodes apparently give a better field, their projection into the field or reduction in clearance reduces the flashover voltage until it is as low if not in some cases lower than the normal gap *A-B*. When we can make use of a dielectric which has a greater strength than air, together with some of the favorable conditions above outlined, it is possible to raise the flashover even for a given clearance far above anything now in use. Air gradient and not string gradient is the real problem.

There are three general schemes which may be used to advantage in connection with steel towers. One is to increase the clearance and improve the field conditions as discussed above. The second is to lower the maximum induced voltage by the use of a ground wire or lower the height of the structure. The third is to control the field in the vicinity of the conductor or at the upper end of the string so that the maximum flashover may be developed for any stress which may exist in operation. This is readily solved by the use of a sphere-gap in the laboratory and it may be approximated for transmission work. In the case of wood supporting structures the problem may be somewhat different as most wood structures furnish insulation which will provide a higher flashover voltage than exists on the largest steel tower line now in operation. The problem in this instance then is to make use of this insulation and increase the life of the structure. Complete impregnation apparently reduces the tendency to shatter and at the same time increases the life. In some cases it is further necessary to prevent burning due to leakage or due to discharge and experimental results would indicate that great improvement in this direction will be available shortly.

In the case of the steel tower, the economic problem is to develop the break-down strength of the air path and in the case of the wood structure to prevent burning or shattering. Much time has been spent on this over a period of years and possibilities in these directions are far greater and more nearly at hand than generally supposed. In many cases it may be advisable to effect a compromise of the several means to get the best economic results. It goes without saying, however, that improved flashover voltage over existing lines must be provided for the large system if high-powered transmission networks are to be extended much further. It seems that this problem together with the use of a lower transmission frequency are the most important ones facing the long high-powered line of the future.

J. H. Cox: Among engineers there seems to be a tendency to question the theory of a phenomenon and to question substantiating laboratory data until the case is proved by actual experience in the field. The theory of the ground wire has long been known. With typical arrangements, this theory indicates that by the use of a ground wire, surge voltages induced by lightning are reduced from about 40 per cent on the top wire to about 25 per cent on the bottom conductor, with vertical configuration. Mr. Peek's work with his lightning generator indicates a still greater protection, or about 50 per cent. Finally, these field experiences of Messrs. Sindeband and Sporn should establish beyond question the usefulness of the ground wire.

It seems strange, with theory indicating as it did a large measure of protection, that when trouble was encountered due to mechanical reasons the obvious solution—that of better mechanical installations—was not practised.

The proper proportion between line insulation and apparatus insulation has received too little consideration in the past. The authors bring up this point. Obviously it is less serious to have a line flashover than a bushing flashover or insulation puncture. During the past two years the Westinghouse Company together with the operating companies, has conducted surge investigations with the klydonograph on a great many power systems. During these investigations, we have conducted tests on 66-kv. lines having line insulation ranging from pin type, or three 10-in. disks to ten 10-in. disks. In spite of the ground wire, we shall always encounter a certain number of flashovers due to direct strokes and the highest induced strokes. More attention should be given this matter so that apparatus is not subjected to these higher potentials by over-insulating the line. On the other hand too low a value of insulation permits an excessive number of flashovers at a voltage lower than necessary and too low to permit the operation of lightning arresters.

There is a point in this question which though evident might bear mentioning. The proportional protection from flashovers afforded by a ground wire is far greater than that indicated by the reduction in surge voltages. If the number of surges between various voltages over a long period are plotted against voltage and a curve drawn through the points a curve is obtained resembling a probability curve as shown in Fig. 2.

If the full line represents the number of surges of various voltages on a particular line without a ground wire, a curve of the surges encountered on the same line with a ground wire

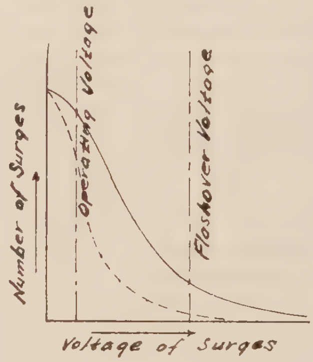

FIG. 2

would be displaced by the amount of the reduction accomplished by the ground wire, giving the dotted line. A vertical line may be drawn at the impluse-flashover voltage of the line in question. The flashovers of the line are caused only by the surges lying to the right of this vertical line. It is clearly seen that the flashover region under the dotted line is less than the flashover region under the full line by more than the percentage reduction.

Our tests with the klydonograph checks the authors' experience in that the highest potentials from lightning were always on the highest conductor and the lowest on the bottom conductor.

There were two points brought out in the discussion towards which I might be able to contribute. The question was asked as to whether flashovers were encountered at some distance from the lightning stroke, indicating a higher potential at some distance from the source. In our experience with the klydonograph, we have never encountered this situation except in the case of a flashover on an isolated-neutral system. We have encountered surges of the order of one million volts and at a distance of 50 mi. no potential greater than normal line potential was recorded. Where the lightning caused a flashover on an isolated-neutral line an over-voltage would be recorded at all stations no matter how long the line. This, however, was due to the acting ground set up by the flashover.

Another question brought up was whether or not the upper conductors afforded protection to the conductors beneath them. From the theory of the ground wire this is not possible except where the upper conductors flashover. The only protection afforded by the ground wire is due to the fact that its charge dissipates to ground with the discharge of the cloud and the

presence of a conductor remaining at ground potential reduces the potential induced on the neighboring conductors. The only way in which the upper conductors could shield the lower conductors is by discharging their charge to ground either by means of the flashover or by lightning arresters.

V. Karapetoff: In considering the influence of the ground wire, it is necessary to distinguish between its effect in reducing the over-voltage and the over-charge. These two effects are expressed numerically by different ratios. Consider the simplest case of a single conductor without any ground wire, with a cloud above charged positively. Then you have a negative bound charge on the wire, with the positive charge conducted to the ground through leakage. When a lightning flash takes place, the bound charge becomes free, so that the protective equipment is subjected, first of all, to an over-voltage, and secondly, there is a definite bound charge which has to be conducted to the ground, say, through a lightning arrestor.

Now consider a ground wire near the conductor. Certain equations may be established for the bound charge, etc. A solution of these equations gives the over-potential to which the line wire is subjected immediately after the stroke of lightning, and also the value of the charge released on this wire as a result of this stroke. The new values of over-voltage and of released charge may be compared with those obtained before, without the ground wire.

As a result of some computations which I have had an opportunity of performing lately, I find the ratio of the two over-voltages to be somewhat different from that of the two charges. Depending upon what you are interested in, that is, whether it is the maximum instantaneous over-voltage or the discharge capacity of the protective equipment (which is bound with the magnitude of the charge and not of the voltage), your judgment about the protective value of the ground wire will be different. My computations, unfortunately, have been made only for this simple combination. It would be desirable to continue these computations so as to include, say, three or six line conductors and a ground wire.

Herman Halperin: In my work as chairman of the A. I. E. E. Subcommittee on Lightning Arresters during the past year, it appeared that the members of the subcommittee and other engineers had many opinions as to the means of coping with lightning disturbances on high-voltage lines, especially those operating between 66 kv. and 154 kv.; but there were little definite data of operating experience, which is the final criterion, to show just what was accomplished by certain types of protection or methods of diminishing the magnitude of lightning voltages. The subcommittee members felt that more operating companies should gather complete data regarding the lightning on their lines, analyze the data, and submit papers along the lines of the one submitted by the authors today. Their paper is especially timely, as it concerns a voltage on which there is considerable discussion. I am sure that the industry will look forward to another paper in two years to compare the coming two years' experience of the authors with ground wires with the last two years, when ground wires were not used on certain lines.

In the future investigations of the authors, it might be well to obtain some data as to the magnitude of transient voltages on their lines, by means of a recording device such as the klydonograph. These data, when correlated with the operating experiences, will give a more definite idea of the effectiveness of the various designs in coping with lightning on their lines.

M. L. Sindeband: Mr. Cox mentioned the problem of insulation. In this paper, we mentioned the matter of over-insulating the transmission line and the bad effect this would have on the equipment in the substations resulting, as it would, in pushing the high voltage from the line into the stations. Of course, the ground wire would leave the transmission-line insulation unchanged but by cutting down the induced voltage it would have a particularly beneficial effect on the substation equipment since, as a general rule, the oil switches and transformers are not insulated as highly as the transmission line.

When we first started this problem and considered the idea of adding more insulators, the manufacturers of equipment objected since they argued that if the insulation of the line is going to be boosted, the insulation of the equipment should be boosted at the same time and they were afraid that this would lead to large expense. If that were done,—that is, if the line insulation were raised,—it does not necessarily mean that the equipment insulation has to be raised likewise since the station and substation equipment has, as a general rule, the benefit of a lightning arrester but the moment you go into that you enter into another controversy—namely, the lightning arrester—and there is almost as much disagreement about that as there is about the ground wire.

Mr. Vincent asked what particular feature of the rings governed their design. We experimented with the design of the rings only in so far as the clearing of lightning flashovers and 60-cycle flashovers were concerned. The wet proposition was not considered at all.

Now as to the table listing the troubles: On our original table sent in to the Institute we had some marks indicating which were under rain conditions and which under purely lightning conditions. Unfortunately, they were left out in printing. However, as we recall it, practically all of these troubles occured during rain periods, that is, they were a combination of rain and lightning.

Fig. 18 is a 60-cycle dry flashover test.

In conclusion, I wish to state that I believe that the operating companies should contribute their bit in helping the manufacturers of equipment with this problem, because certainly the manufacturing companies do spend a great deal of time and money for this purpose.

AUTOMATIC AND SUPERVISORY CONTROL OF HYDROELECTRIC STATIONS

(Smith)

Niagara Falls, N. Y., May 28, 1926

W. H. Gerrie: It may be of interest to relate some operating experiences in connection with two such plants as Mr. Smith has described. The plants I refer to are on the Central Ontario System of the Hydro-Electric Power Commission and consist of three generators per plant, the capacity of the units in the one being 2000 kv-a. and in the other 1400 kv-a. Excitation is supplied by direct-connected exciters and control by one regulator of the vibrating type in each plant. The plants are located on a navigable stream, the levels of which are required to be maintained within very close limits. Both plants are controlled from one point and the operator in charge has to operate in addition the plant where he is located, which has a capacity of 9000 kv-a.

The following satisfactory points have been observed up to the present:

(1) The reliability of the sequence relays.

(2) The saving in time of bringing on generators by the self-synchronizing method.

(3) The apparent reliability of the supervisory equipment.

In connection with the second point it is interesting to note that we are obtaining satisfactory results with the self-synchronizing method on generators that are not equipped with damper windings, but which have solid field poles. This is in part contradictory to the statement contained in Mr. Smith's paper.

Our experience so far has shown that we have had more troubles due to dirty contacts and sticking supervisory relays than we have had with the sequence relays. While their operation has given a fair degree of satisfaction, the troubles we have experienced point to the necessity of having a specially trained man available to analyze and eliminate these troubles with the least possible delay.

Some of the points on which we are rather skeptical at present are as follows:

(1) The economy of this system of control where less than four plants are so operated in the same territory.

(2) Whether the governors will perform satisfactorily enough to insure reliable operation after they have been in service for several years.

(3) Whether the method of controlling excitation by one regulator should be encouraged where several direct-connected exciters in the one plant are used.

(4) The proper method of obtaining battery-charging supply.

(5) Whether the remote meters as they at present exist are sufficiently reliable for satisfactory operation and for system operating records.

Elaborating on these, I might say that it is desirable to have an attendant available at each plant for ordinary cleaning who can be called out in cases of emergency. Also it is desirable to have a specially trained man for ordinary inspection who, in case of trouble on the supervisory or sequence relays, can locate and remove the trouble with the least possible delay. Under normal conditions this man should be able to handle four or five plants. Where only one or two plants are in service, the cost of his time together with the carrying charges on the additional capital cost of the plants does not leave sufficient margin to say definitely that the remote-control plant is justifiable. The same is true of the governors. These devices should have expert inspection and adjustment and this is not always available on small systems.

We have had considerable difficulty in obtaining balanced reactive loads with balanced kw. loads between generators in the one plant. This may become serious enough when operating at full kw. load to introduce excessive heating, causing the generator to be tripped off by thermal protection when it can least be spared. This trouble is directly attributable to the regulator operating under the above mentioned condition.

We have in use at these plants two systems for obtaining battery-charging supply, *viz:* (1) from the exciter system, and (2) from rectifiers. The first is impractical in that it cannot follow the ordinary system voltage variations between day and night conditions and between week-day and week-end conditions. The latter difficulty is particularly aggravated where a holiday follows a week-end. Also there is considerable inconvenience from blowing fuses on high excitation which, when it occurs, causes the battery to go on discharge. The rectifier has not as yet proved that it is reliable. It would appear that the most satisfactory results should be obtained from the motor-generator charger.

Two methods of remote metering in use are (1) current method and (2) impulse (condenser) method. While the latter method has given fair results, it is not without certain inherent defects the most serious of which is that variable control voltage will change the calibration. The time lag to the meter also is not a desirable feature when adjusting load on the plant. Extreme warm weather also affects the viscosity of the damping fluid to such an extent as to give an entirely different chart, although the actual frequency regulation may be the same. Also some of the condensers have become defective. Indications so far point to the current method as being the most satisfactory that we have experienced.

The operating company must thoroughly appreciate the manufacturer's difficulties in development in a new art such as this and be willing to cooperate in supplying operating data so that faulty applications may be weeded out. The manufacturer on the other hand must fully appreciate his responsibility in the development of a new art and wrong applications must not be permitted to get out into the field.

Another point that should be emphasized is the necessity for competent centralized supervision of such installations. The whole work should be under the supervision of a competent field engineer who is able to correlate all sections of the work.

It is also very important that manufacturers make a thorough analysis of system operating conditions before proceeding with any installation and the operating companies should lend all assistance possible in supplying the necessary operating data.

In Mr. Smith's paper I note that in section (G) he refers to shutting a unit down when the voltage drops to 80 per cent of normal for several seconds. In actual practise this works out as unnecessary protection and we may find the system dropping load on ordinary system surges.

Reference is also made to the use of annunciators for bringing to the attention of the attendant troubles of a serious nature. It cannot be emphasized too strongly that these annunciators should be very reliable. Also it has been my experience that the tendency is to have an insufficient supply of them.

Mr. Smith says that the multiple-unit station gives rise to no particular problem. I would like to draw attention, however, to the complications of such a system. It seems to me that the division of excitation is a real problem. Mr. Smith refers to one installation for the New England Power Company using direct-connected exciters and separate regulators. A description of the method of voltage control, in the light of the difficulties that I have already mentioned in using the one regulator, would be of interest.

Mr. Smith refers to the fact that in general the direct-connected exciter is by far the more desirable for automatic control. It might be of interest if Mr. Smith would elaborate on the various reasons for this statement. Also in applying this system of control to old stations which generally have the motor driven and turbine driven exciter, it might be of interest to know whether any problems of a particular nature would be introduced. It seems to me that the question of excitation unbalance between generators referred to above would be entirely eliminated with the one exciter, but it may be that other complications are introduced which make the direct-connected exciter preferable for automatic stations.

C. F. Publow: I would appreciate having Mr. Smith give details regarding the following functions which he notes automatic equipment is generally arranged for.

(1) Item "D": Protection against motoring the generator. We have found that owing to the changes in system frequency between the time a unit is shut down and started again, although of a very small order as will be shown later, yet when a unit is brought on it occasionally closes its gate tight and motors on the line until such time as the operator discovers the situation and corrects it. This in many instances would take upwards of at least a minute and I am interested in knowing what form of protection has been found suitable for such cases, as I believe this performance will be common to any system and more especially to some of the ones Mr. Smith refers to where the frequency varies upwards of five per cent.

(2) Item "F": Charging the battery. I would be interested to have Mr. Smith state definitely what method of battery charging he refers to. We have two methods (from rectifiers and from exciters where vibrating type regulators are used) neither of which has proved satisfactory.

I note Mr. Smith refers to using the exciter voltage for operating a speed device for placing a unit in service at approximately synchronous speed. How closely can this method be depended on to repeat itself? It would appear to have the disadvantage of having no protection for high exciter voltage, which would occur on overspeeds.

I was particularly interested in Mr. Smith's description of the connections used in mounting the protective equipment for the supervisory connections between stations, and I would appreciate a statement as to the functions of the various parts of this protection.

I would appreciate getting an expression of opinion on the following:

(1) The desirability of grounding the positive terminal of the

battery which supplies power to the automatic telephone type of supervisory equipment.

(2) The use of oil dash pots for controlling the governor during the initial starting period. This type of control has the disadvantage of (a) permitting "creeping" and (b) variations in its performance due to temperature changes.

In this connection I would like to ask if a motor connected to the governor stop control lever has ever been used. It appears to me that this device could readily be adapted for this work and overcome the two disadvantages noted above in an oil dash-pot control.

(3) The most desirable source of energy for the motor-driven governor fly-ball. Use has been made of potential transformers on the two stations on the Commission's system, but this supply is of no use in event of a machine pulling out of step. Slip rings connected to the exciter and mounted above the commutator would seem an ideal source of power supply for this important service if it can be obtained at a nominal cost.

(4) What would be considered a satisfactory value in ohms of a station ground in an average hydroelectric station, where remote supervisory installations are applicable.

Remote supervisory control to be successful is dependent on:

1. Reliable control circuits connecting the control and remote stations. These should remain intact except in cases of direct lightning strokes or where a high-voltage line falls on them and in such instances the protective equipment should function to limit the damage done to the point where the fault occurred.

2. A signal once started by the operator at the control point or automatically by the equipment at the remote station must repeat itself until the "answer back" or equivalent is received which de-energizes the repeating circuit; *i. e.*, indications must be correct, or by repetition warn the operator that trouble exists, and the design of the equipment should incorporate the feature that the equipment at the two ends will re-synchronize before repeating the code.

3. The equipment in its design must incorporate No. 2 above and be mechanically rugged enough to perform the service required of it with a minimum of maintenance.

4. Means should be provided which will permit canceling a supervisory signal where one has been put through and the automatic sequence has failed to complete its function at the remote stations. Under such circumstances the operator may be helpless and considerable damage may result before an attendant can be rushed to the remote station. This feature seems desirable in addition to the automatic sequence scheme being arranged to permit only one start, in event of trouble, unless the supervisory signal is repeated.

5. When there is a considerable number of indications, some are much more essential than others and it may be desirable to have incorporated in the supervisory scheme, means of giving these more essential signals precedence over the other. In all cases I believe it would be advisable to give order signals from the control station precedence over signals originating from the remote stations.

6. A high degree of maintenance care. This should be generally in one individual's charge who is fully familiar with the circuits and the operation of the equipment.

Automatic switching equipment can be made thoroughly reliable by adhering to the following points:

1. That the sequence scheme is well adapted for the work it must perform.

2. That suitable relays and corresponding equipment have been chosen which will always perform their function accurately whenever required and failing this will make the sequence inoperative.

3. That a proper assembly of this equipment has been carried out. This applies to their location and connecting with a view to their particular function from a safety standpoint and also with ease of maintenance. It would seem desirable that all contactors should be provided with positive wiping contacts which will assure good contact even though they are dirty.

4. That the equipment should be carefully adjusted by thoroughly competent men when installed, to perform their particular function so accurately that they may be depended on to "repeat" and that for the first few months this performance be carefully checked and an accurate record of it kept. This record will serve as a guide to the frequency of inspection required in the various parts later on. The speed device is an exceptionally important one to which the foregoing comment is particularly applicable.

5. Workmanship of a high order is required on the various devices used and in their assembly.

6. A competent maintenance man should be in charge of the equipment. It is essential in maintenance work to be observant of equipment the functioning of which will inherently vary with weather conditions, and in this connection I believe manufacturers should supply data on the performance of their equipment of this nature. This will materially assist the operating companies in making the needed adjustments and in this way they will be warned of the necessity of watching these points carefully. The dash-pot control of the governor for controlling the unit during the starting period is a good example of this type of device.

In the installation and initial operation of both supervisory and automatic equipment, too much care cannot be taken in accurately checking, point by point, every piece of equipment.

The following points should be given attention:

(1) Careful consideration should be given to the mechanical work where devices are attached to the generators in order to avoid their being damaged during disturbances.

(2) The brakes should be interlocked mechanically and electrically so that they cannot be applied with the unit connected to the system.

(3) Trip-free devices should be furnished if this feature is not incorporated in the sequence relays.

(4) The choice of air or oil brakes should be given serious consideration. We have oil brakes on all six units and so far it has been impossible to make them oil-tight.

(5) The inherent characteristics of each individual device should be thoroughly known in order that under the different ordinary conditions which will occur in the actual operation of station they will inherently correct for the variations from normal.

As stated in the foregoing, the supervisory control circuits connecting the control and remote stations must be practically invulnerable. These circuits may be affected whenever a disturbance occurs on the transmission lines, which they usually parallel, and unless special precautions are taken, the control circuits will be inoperative just at the time when they are most needed, and this from an operating standpoint is a very serious condition. For nearly a year and a half, serious troubles have been experienced by the Commission, on the control circuits to the two supervisory stations mentioned by Mr. Gerrie. By exhaustive testing and analysis, the inherent weakness has been located and by the installation of protective transformers, now being built, the supervisory circuit should be immune from all transmission line troubles, except a direct stroke of lightning or where a high-voltage line falls on the supervisory control circuit.

The stations in question are Ranney Falls the control point, Dam No. 8 and Dam No. 9. The distance from Ranney Falls to Dam No. 9 is approximately 1½ miles, and to Dam No. 8 is 3½ miles. They are connected by one 44-kv., 3-phase, 60-cycle line which feeds out of Ranney Falls and loops in to Dam No. 9 and Dam No. 8, and thence to Sidney Terminal Station some 20 mi. south, a line which forms part of a 44-kv. network of some 400 mi. of line and which is complicated by several loops. The supervisory connecting wires consist of standard paper-insulated, lead-covered telephone cable located on the same right-of-way as the 44-kv. line, but on a separate pole line at an average distance of 25 ft. from the

high-voltage line, a 20-pair cable between Ranney Falls and Dam No. 9 station and a 10-pair cable between Dam No. 9 and Dam No. 8 stations. Twelve conductors are required under the existing conditions for the control of each station and 66 different operations are performed besides the metering and water-level measurements at each station.

In each of the remote stations there are three generating units which with their respective step-up transformer constitute a unit. The generators in both stations are vertical, water-wheel driven units with direct-connected exciters. The units are of 1400-kv-a. capacity at Dam No. 9, and 2000-kv-a. capacity at Dam No. 8.

It may be of interest to note that the turbines in Dam No. 9 are of the propeller type and the generators are equipped with damper windings while at Dam No. 8 the water-wheels are of the Francis type of runner, and the generators are not equipped with damper windings. Self-synchronizing of the units is employed in both stations. This practise at Dam No. 8, from current literature, would appear as questionable practise, but results have proved it very successful. It should be noted, however, that the generators in this station have solid field poles.

Induction was first thought to be the trouble, but an analysis indicated that the burn-outs were much too severe to be caused by it under the existing conditions. It later was discovered that on account of the high-voltage neutral being grounded to the station ground at the control point, the lead covering of the supervisory cable was acting as a ground stabilizing conductor whenever faults occurred on the high-voltage transmission system with a flow of ground current. By removing the high-voltage neutral ground at the control point approximately 1000 ft. from the station, trouble of this nature was mitigated except where due to a lightning-arrester discharge or an insulator spillover at the control or either of the remote stations. The system is operating at present under this hazard with operators maintained in both the remote stations. The protective transformers referred to in the foregoing are designed to make the supervisory cable immune from these troubles.

For a period of approximately three months during the past winter, the supervisory control was not in operation. When again placed in service, very little trouble was experienced, and only a few cases of mechanical trouble have occurred in the past two months, a performance very creditable to the equipment.

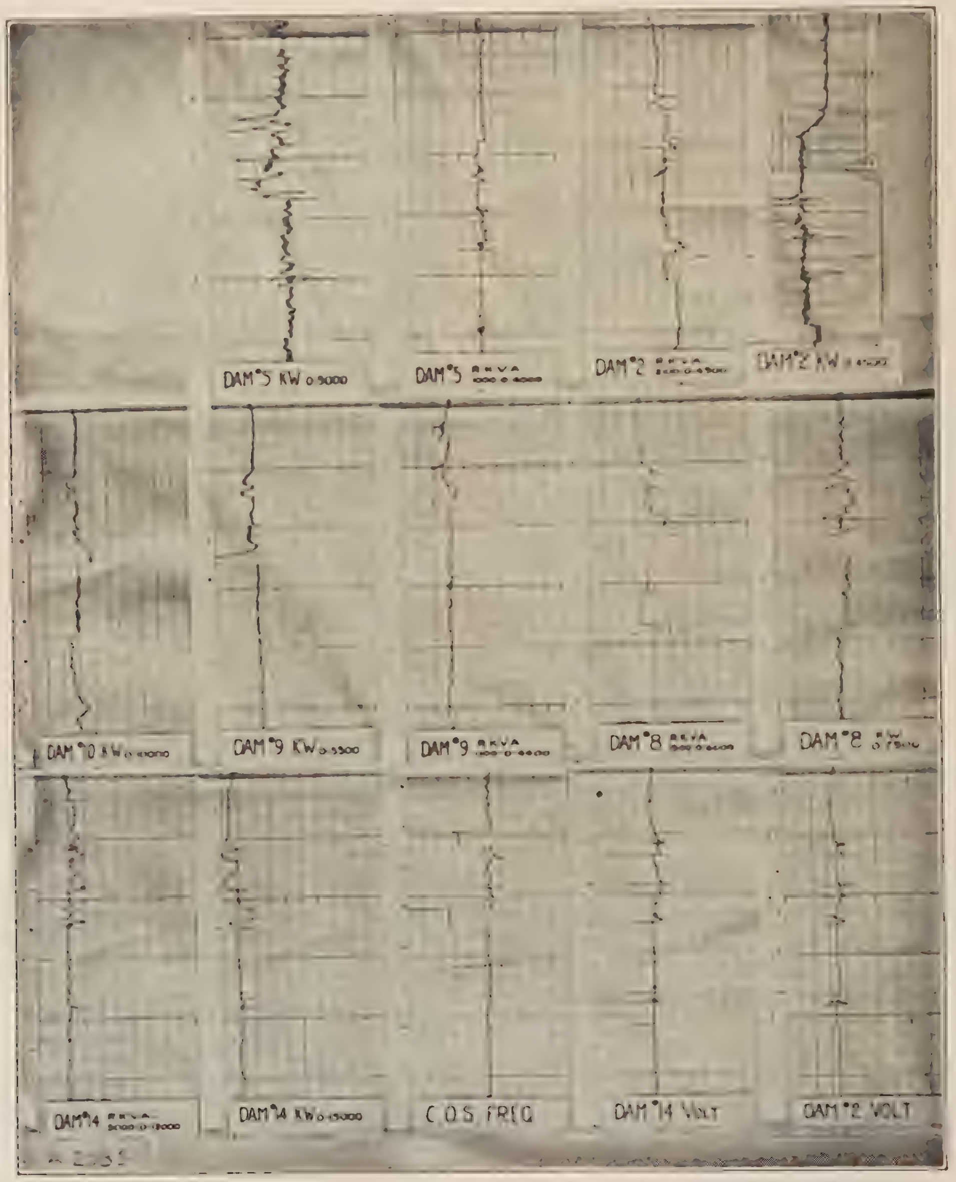

FIG. 1

Dependence is not yet placed in the control and operators are still on duty at the remote stations.

In attacking the problem of the installation of operation of the automatic and supervisory stations, an effort was made by the Commission quickly to acquaint its staff of engineers and operators who were to be directly responsible for the installation and operation of these stations with the details of their connections by preparing unit diagrams of correlated devices; *i. e.*, the automatic connection diagrams as supplied by the manufacturing companies were split up. A corresponding drawing of the governor was also prepared. These have been of untold value and still form a ready reference.

Fig. 1 shows a number of graphic meter charts taken during a period of several hours on the morning of September 18th, 1925, at which time there was a severe electrical storm over the entire system. Note how closely the frequency is regulated even during such a time. This group of charts forms a very interesting study of this system's operating characteristics.

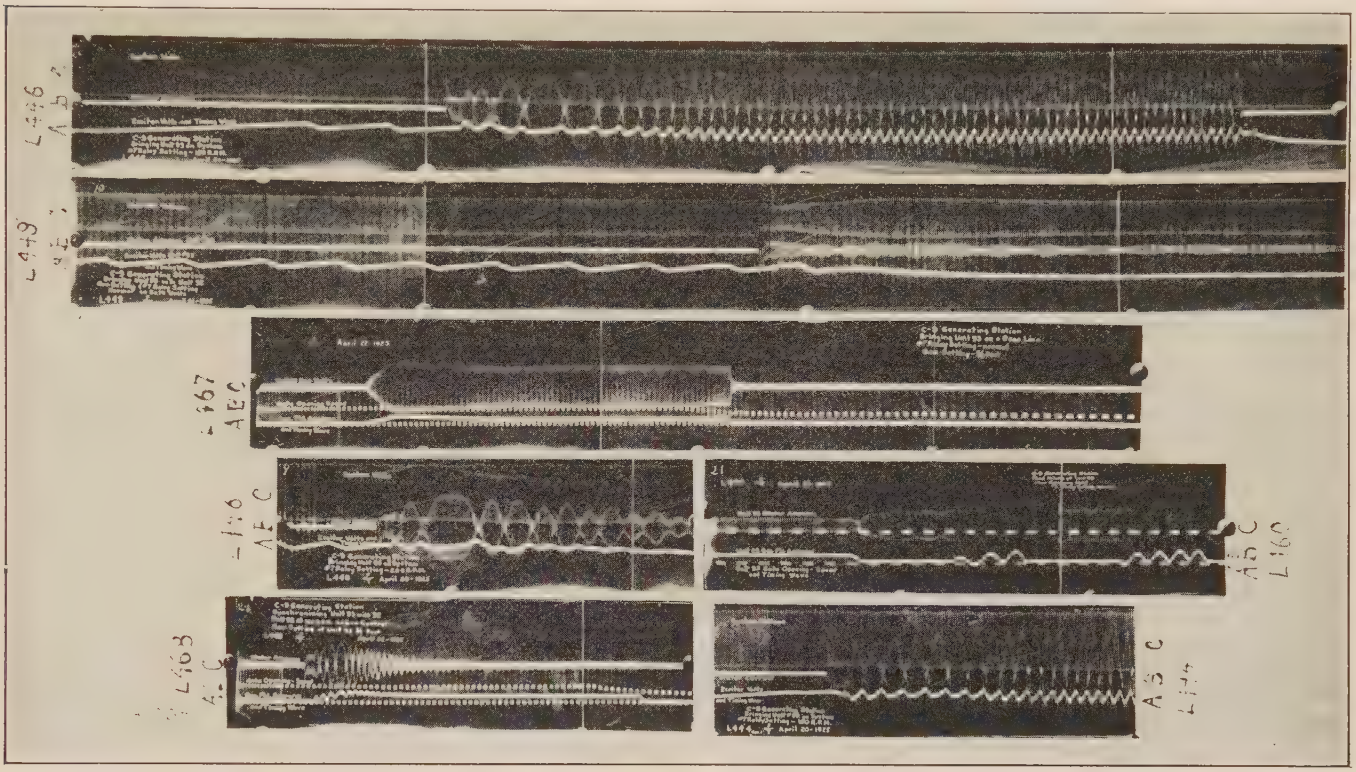

FIG. 2

Fig. 2 shows a number of oscillographs which form part of the test on the performance of these stations.

I feel that much more successful tests could be obtained now, as a decided improvement has been made in the regulator and governors and speed control adjustments since the tests referred to in the foregoing were conducted and these changes would vitally affect the performance of the equipment. The oscillographs shown refer only to Dam No. 9 station; those obtained for Dam No. 8 station were equally successful, the disturbances of course being considerably different due largely to the differences in design of both generators and turbines. It may be interesting to note that on a number of the oscillographs referred to, as many as five quantities are readily readable on a three-element oscillograph. For measuring speed on these, a chronograph method, similar to that used by Mr. J. A. Johnston but developed independently by the hydro engineers, was used with success.

A. G. Darling: The problem of self or automatic synchronizing has been very much discussed. I want merely to cite two cases of self synchronizing under very difficult conditions which have been successful.

One case was in a paper company which uses power to drive paper machines which require very close speed regulation. This particular case involved a 750-kw. steam turbine generator and an auxiliary 3000-kw. steam turbine generator. The first was non-condensing and was used to supply power directly to the paper machines while the second was put on the line when the power company did not have sufficient power available to furnish power for the balance of the mill. They were operated in parallel.

The operator in charge had great difficulty in bringing in the 3000-kw. machine by the usual method of exciting first and then synchronizing by a synchroscope without breaking the sheet on the paper machine.

He asked for advice on the point and it was suggested that he bring in the 3000-kw. unit by the self-synchronizing method, that is to say, put it on the 750-kw. turbine without its field being excited. His success after that was uniform. He did not have to depend on the operator's accuracy and his sheet was not broken when synchronizing the 3000-kw. machine.

The second case is of another paper company in the middle west which operated two steam-engine-driven paper machines. In addition to the paper machines, 200-h. p. synchronous motors were directly connected to the engines.

Initially these two motors were supplied from the power company in the vicinity without a great deal of success because the speed regulation of the power company system was too wide to permit paper being made consistently for 24 hrs. The paper company owned a hydroelectric development nearby and installed there three 2500-kw. units. One unit was on the line all day long and the other two units came on and went off as the water level increased and decreased during the day, so that there were two operations of synchronizing and two of coming off the line during every 24 hrs. These machines were put in parallel with

the 200-h. p. synchronous motors on the paper machine drive and were self synchronized.

The plant has been operating for two years, I believe, and they have had no difficulty with breaking the sheet of paper when the 2500-kw. units are put on in parallel with 200-h. p. motors.

F. V. Smith: Mr. Darling's experiences with the difficulties encountered with manual synchronizing and the success of self-synchronizing methods are interesting and bring out strongly the necessity for very accurate synchronizing in some cases. The average paper-mill operator cannot always be expected to hit the mark and it is apparent that if a machine is excited and thrown in out of phase it will produce more disturbance than if put on the line as an induction motor. With a reliable means of assuring proper phase relations as is done by the automatic synchronizer the disturbance would be reduced to practically zero.

Mr. Gerrie also has mentioned successful self-synchronizing with machines without dampers. This is sometimes a possibility and should always be tested out in case of old machines that are to be made automatic and are not provided with dampers. In certain cases with a large number of solid poles sufficient current will circulate in the pole faces to pull the machines into step. This is the exception rather than the rule, however.

Mr. Gerrie and Mr. Publow have brought up a number of points which will be covered in order.

As to the economy of supervisory control installations, every problem has to be treated separately. Proper inspection and maintenance is, of course, necessary but any operator capable of testing and adjusting relays should be able to handle the supervisory control without difficulty. There are many systems operating with only one or two plants and finding it quite economical. There is no reason why the governors should not function as satisfactorily after years of service as any other piece of equipment.

As to regulators, by far the most satisfactory arrangement is to have a separate regulator for each machine. Proper division of reactive current can then be secured without any difficulty by proper cross compensation; any instruction book on regulators will explain this connection.

In general, the battery should be charged from rectifiers. This is particularly true where a regulator is used on the exciter and the voltage varies over quite a range. The control for rectifiers is quite simple and most suitable for automatic stations. There is no fundamental objection to a motor generator except the additional expense and complication of control which is not in general felt to be justified.

The integrating type of remote metering should be perfectly accurate while the graphic type should be accurate within three per cent which is comparable with any graphic meter. The various types of metering schemes available have their application depending on the kind of indication required and the length and characteristics of the control circuit. In adjusting load the time lag in the meter should be no greater than that in the governor and gate mechanism and it is difficult to see that this is of any particular moment. Any operator would naturally wait for a few seconds after changing load before making another adjustment.

Both Mr. Gerrie and Mr. Publow refer to the failures of supervisory-control cable when faults occurred on the high-tension line owing to lack of foresight in locating the station grounds. It is to be hoped that this experience will prove of value to others.

The question as to the setting of low-voltage relays and the number of annunciators provided can always be adjusted to the satisfaction of all concerned.

As to the multiple-unit stations, where individual regulators and direct-connected exciters are used with rectifier control for the battery, the problem is not difficult to handle. The parallel operation of regulators has already been mentioned.

The direct-connected exciter is particularly advantageous because of the elimination of all starting or governor control for a separate motor-generator set or water-wheel exciter together with the protective apparatus that would have to be provided. The time of starting and getting on the line would also be delayed by the time necessary to start the exciter and another link would be added in the chain which should be made as simple as possible in all automatic stations.

Mr. Publow brings up a number of points that have already been covered. The shutting down of a generator due to high frequency on the system has not been encountered to any extent. It is difficult to say why it would not be satisfactory to set up the governor to the top frequency limit so that the automatic generator would tend to take load rather than shut down and then by means of supervisory control the load can be adjusted afterwards to suit.

The application in which exciter voltage is used to determine approximately synchronous speed is one in which the automatic generators are small in comparison with the whole system and accurate adjustment is not necessary as the current surge on closing the breaker is unimportant. This does not interfere with over-voltage protection of the exciter.

The arrangement of protective tubes has already been described in the paper; there is nothing further to add on this point.

Mr. Publow has listed a number of points on which successful supervisory control is dependent. I find myself in hearty agreement with these; they are all incorporated in the code type of supervisory control. Also automatic switching is in general in accordance with the factors mentioned.

As to the desirability of grounding the battery, it is found much more satisfactory to keep the battery circuit entirely isolated so as to prevent any faulty operation by accidental grounds.

Difficulties with the oil dash-pot for governor control have never been found to be of any importance and as far as is known it has never been felt necessary to use a motor mechanism.

The same feeling exists as to control for the governor motor; while it is open to objection at times the change suggested has never been felt warranted. There is no objection to it, however.

It is not possible to give a definite figure for ground resistance; that which would be satisfactory in some cases would be quite unsatisfactory in others. The essential point is that the ground resistance should be such that is is considerably less than the path provided through the supervisory circuit which can be determined for any particular case.

There is a last important point which must be considered and which has been mentioned by both discussors, and that is the relation of the manufacturer to the installation and operation of the equipment. While it is the duty of the manufacturer to furnish the apparatus with complete information, it is a question whether it is desirable that he should take care of all the installation and initial operation. As the operating company's men must ultimately take charge of everything and also correct troubles when they occur, there is no way for them to become better acquainted with the details than in the erection stage and the more they have to do with it the better; they will then feel enough confidence to go ahead when difficulties occur. Many operators feel that there is something mysterious about automatic control. There is no justification for this attitude and there is nothing in automatic and supervisory control that cannot be handled by intelligent operators without constant appeals to the manufacturer.

These tests were made on 1400-kv-a, 180-rev. per min. units driven by propeller-type turbines.

In L 446 it is interesting to note what a slight disturbance was noticeable in the system voltage when a unit was placed on the line and failed to "pull in" due to its slow speed. The machine was thrown on the system when it had a speed of 150 rev. per min. Curve A shows exciter voltage and timing wave. Curve B shows stator amperes. Curve C shows system voltage.

L 499 shows a unit synchronized with a duplicate unit carrying

no load and although an abrupt voltage disturbance occurred it was practically damped out in a second. Curve *A* shows exciter voltage on the unit being synchronized. Curve *B* shows stator amperes on the unit being synchronized. Curve *C* shows voltage of the running unit.

L 467 proves how smoothly and quickly an isolated unit can be placed in service on a system. Curve *A* shows field amperes and timing wave. Curve *B* shows gate opening and speed. Curve *C* shows generator voltage.

In L 448 where the unit failed to "pull in" due to overspeed, there will again be noted the slight voltage disturbance which occurred and also the peculiar alternately large and small stator-current disturbances. The machine was connected to the system when running at 200 rev. per min. Curve *A* shows exciter voltage and timing wave. Curve *B* shows stator current. Curve *C* shows system voltage.

A severe test of field failure under load is shown in L 460. Apparently there was no tendency for this unit to pull out of step at the load carried. Curve *A* shows gate opening, speed and timing wave. Curve *B* shows field current. Curve *C* shows stator current.

The test shown in L 468 was performed to illustrate the ability of a unit (No. 93) to pull into step with a duplicate unit (No. 92) running under no load at a reduced frequency. Unit No. 92 was running at 160 rev. per min. on governor control. The governor of No. 93 was set for highest speed. Curve *A* shows generator field amperes and timing wave. Curve *B* shows gate opening and speed. Curve *C* shows stator amperes.

L 444 shows the failure of a unit to pull into step when connected to the system while running at 150 rev. per min. Curve *A* shows exciter voltage and timing wave. Curve *B* shows stator current. Curve *C* shows system voltage. This, it should be noted, is a duplicate of L 446, but the initial disturbances are quite different.

STEEL-ENCLOSED POWER RECTIFIERS[1]

(MARTI)

NIAGARA FALLS, N. Y., MAY 27, 1926

R. H. Wheeler: Mr. Marti has been quite conservative in many statements in his paper. Progress in the development of the rectifier, together with its applications in commercial service, is going forward at a rapid rate. One thing that Mr. Marti did not bring out, and which from my angle is interesting, is that the rectifier is a piece of machinery which has the ability of being placed in practically any available space, rather than demanding a machine hall with ample provision for ventilation. The floor loadings required by the rectifier are less than 200 lb. per sq. ft., and permit of the rectifier being installed directly without special foundations.

I wish to confirm the statements of Mr. Marti as to the absence of noise. There are no reciprocating parts other than that of the vacuum pump which, when it is running, makes a chatter, but when one realizes that it is operated by a fractional h. p. motor, it is at once evident that the noise is not great and can easily be muffled by a cover if absolutely noiseless operation is desired.

Otto Naef: Mr. Marti mentioned that in order to obtain close d-c. regulation, special equipment must be added, and he quoted the interphase transformer, or absorption coil, as it is often called, as one of the means.

After considerable research, Brown Boveri has succeeded in bringing out a zig-zag-connected transformer winding which gives the same close regulation as is otherwise only obtained by the use of an interphase transformer. Because of the somewhat larger transformer required, this solution is not necessarily cheaper than the older method, but it has the advantage of greater simplicity.

1. A. I. E. E. JOURNAL, Sept. 1926, p. 832.

D. C. Prince: Mr. Marti refers to an ingenious seal as having made possible the successful steel-tank rectifier. The accompanying Fig. 1 shows one of these earliest types of steel rectifiers, built about 1908. The operation of these early rectifiers compared favorably with that of any of the newer types.

In saying that the quantitative relations on which rectifier design is based are well established, Mr. Marti doubtless refers

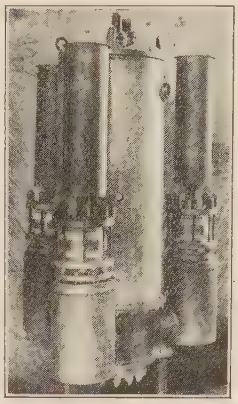

FIG. 1—EARLY TYPE OF STEEL-CLAD MERCURY-ARC RECTIFIER (1908)

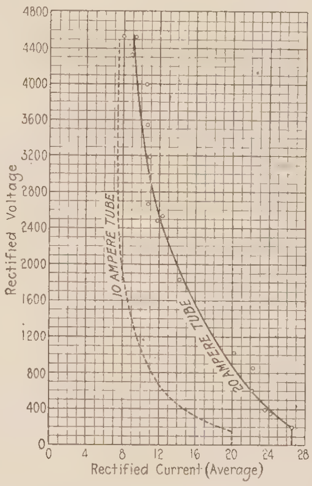

FIG. 2—VOLT-AMPERE CURVES MADE FROM GLASS RECTIFIER

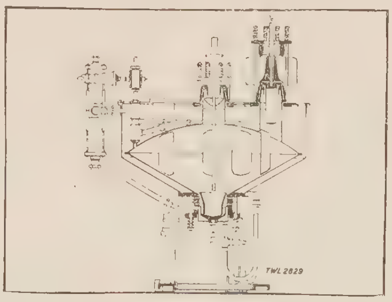

FIG. 3—A. E. G. TYPE OF RECTIFIER

to the circuit characteristics. As far as I am aware, no data for metal rectifiers have been published including reproducible curves between volts and amperes at which arc-back occurs, such as shown in Fig. 2 herewith. This curve was made from a glass rectifier.

The extent to which engineering opinion differs regarding the fundamentals of steel rectifier design is brought out by comparing the accompanying Fig. 3 with the Brown Boveri

rectifier shown in section in Mr. Marti's Fig. 10. It will be observed that the A. E. G. type has no arc guides and no condensing dome nor any elaborate anode hoods. The A. E. G. rectifiers are regarded as highly successful, and there are many installations. I understand that they have little if any seal trouble.

Even the figures accepted for some years for cathode drop have recently been overthrown[2]. The present figure is about 10 volts, part of which is consumed as latent heat of ionization of the mercury vapor. This part is responsible for most of the heating at the anodes where recombination occurs.

Too much cannot be said in praise of the paper by Messrs. Daellenbach and Gerecke referred to by Mr. Marti as the basis for his circuit theory. The part quoted by Mr. Marti, applying to regulation, is limited to the case of no resistance and reactance only in the individual anode leads. It is also limited to the case where not more than two anodes carry current simultaneously. The original paper by Messrs. Daellenbach and Gerecke is much more complete and will repay careful study, although the analytical methods pursued become rather involved for the more complicated cases met in practise. Their paper has been very useful in my work.

E. B. Shand: A number of years ago the Westinghouse Company did a great deal of work on steel-tank rectifiers, and a resumé of this was given by the late B. G. Lamme in the discussion of "Power Rectifiers" by Milliken, *Proc.* Assoc. Iron & Steel E. E., 1921, p. 645. In this work, we started using mercury seals with the steel tanks in 1908 and developed them in 1909 to the general type used at present by the Brown Boveri Company. In 1915 considerable amount of work was done on plastic sealing cements. Our experience at that time indicates that the tightest possible joints can be made by this means, although the application to commercial use presents an additional problem. At this time we were able to operate rectifiers of commercial size with these seals for periods of somewhat over a month, without pumping. Welded tanks were introduced in 1910.

I might add that the wire resistance gage for high vacuum, which is mentioned in Mr. Marti's paper (Figs. 16A and B), was developed during this work in 1916 or '17. I still have in the laboratory a gage of this sort which dates from the above period.

A single auxiliary anode was used for both starting and exciting of the rectifier. An external source of direct current was supplied to this anode. Small rectifiers are now available for the purpose of furnishing this power and which require no attention of any sort.

In connection with the bibliography, I believe that the interesting papers of M. Giroz[3] should be included.

In connection with the tabulated data on the sixth page of Mr. Marti's paper, I notice that the case of three single-phase transformers connected in star has not been included. In this case, the current ratios in the transformers secondaries and in the primary line are similar to the case of the delta-connected transformer with the balance coil.

It might be added that the balance coil or interphase transformer was developed in connection with the earlier work of the Westinghouse Company by Mr. C. L. Fortescue.

S. Q. Hayes: A point that may be of interest to a good many people is that the electrification of the railways in Japan now being carried out at 1500 volts direct-current has quite a large number of substations, and some of those substations have synchronous converters, some have motor converters, some have motor-generator sets, and some have mercury rectifiers; and they are operating the whole system together in parallel.

F. A. Faron: Mr. Marti infers in his paper that arc-backs occur during the bake-out or forming period. Are we to understand that arc-backs never occur during regular operation?

On the twelfth page Mr. Marti refers to the possibility of a rectifier starting to take peaks of such short duration that converter units would miss these peaks. What he says about starting may be true, but why should a machine be started to take care of such peaks? This is what the overload capacity of the machine is for. And if the load goes beyond this allowable limit, it is not usually a useful one and devices are provided to take care of limiting the output. With reference to regulation, it should be noted that it is possible, as brought out by Mr. Prince, to build rectifier equipment with practically flat d-c. voltage characteristics from low load to full load.

Mr. Marti indicates that traction loads are handled by converting equipment with drooping characteristics. This is not quite correct, for in 90 per cent of the traction substations in this country, compound-wound machines are used, having practically flat voltage characteristics from no load to full load.

Fig. 20 is apparently based on a maximum rated unit. Experience has shown that railway operators are not particularly interested in a maximum rating but in what the machine will do for a period of about two hours, which is the usual duration of peak service. This is fairly well brought out in Curve 21-*B*, on the same page. In comparison with Curve 20, it should be noted that a standard 500-kw. railway converter, for instance, would be rated 750 kw. for two hours and three times load for one minute.

Does Mr. Marti intend to convey that all equipment including rectifiers, transformers, auxiliary devices and switchboard for 600 volts take about the same space as complete converter equipments, or does he mean only the tanks? I am of the opinion that the complete installation of rectifiers, transformers, reactors, accessories, switchboard, etc., occupy more space than equivalent converter capacity for this voltage. I agree with Mr. Marti that, for higher voltages, the complete rectifier units require less space than converter units.

In traction work it is quite common to provide single-phase transformers which give the possibility of open-delta operation of converters in cases of emergency. This feature is not desirable in connection with a rectifier.

Under the subject of starting it should be noted that in automatic stations it is usually found more economical to remove the transformer from the line when the station is not in operation, to save the transformer excitation losses.

I have been unable to check the figures given under the heading *Efficiency*, as the converters offered by American manufacturers have higher efficiencies than those shown on the curves of Fig. 21A and actually cross the efficiency curve of the rectifier at about 600-kw. point, and show somewhat over one per cent higher efficiencies of the converter than Curve *A*, which reduces the hypothetical saving set forth by Mr. Marti.

I am fearful that "automatic control" is a rather abused and misunderstood term, but it should be understood as applying to a station wherein all functions of operation are performed without the aid of an attendant.

Certain functions necessary to the operation of a rectifier, which are absent with converter operations, must be properly incorporated in the control, and protection provided should the sequence of the device in operation be other than that intended.

There will be certain temporary shut-downs during operation which the control must take care of; such, for example, as low a-c. power supply, single-phase operation, overheating of the rectifier, failure of the exciting arc and overheating of the transformers.

Furthermore, such conditions as failure of cooling-water supply, continued arc-backs, heavy sustained overloads, etc., require that the equipment be shut down and locked out, and

2. Günther-Schulze, *Engineering Progress*, Aug. 1925, (in English).

3. Les Redresseurs a Vapeur de Mercure, *Bulletin de la Societe Francaise des Electriciens*, June, 1924, p. 463.

Les Redresseurs a Vapeur de Mercure Grand Debit, *Revue Generale de l' Electricite*, Nov. 20, 1920, p. 721.

La Chute de Tension Inductive des Redresseurs a Vapeur de Mercure, *Revue Generale de l' Electricite*, Feb. 14 and 21, 1925, p. 253 and 303.

that the automatic control be designed to carry out these functions.

Incidentally, a very careful investigation has convinced me that there have been no rectifiers built which will not arc-back if the vapor-pressure conditions in the neighborhood of the anode are not correct.

Mr. Marti says: "For instance, a railroad equipped for using 600-volt direct current can be changed to 1200-volt direct current merely by changing the connections of the transformers and making no changes whatever in the rectifiers." It is one of the advantages of rectifiers to be able to use the same unit for higher voltages, provided it is suitably insulated;—but unfortunately the substation is only one thing that must be changed; in fact, changing the substation voltage, even where converters are used, is a relatively small expense compared to insulation of line, sectionalizing switches, motors, control, etc.

The substation of the average traction system in this country represents only an investment of about 20 per cent of the total investment in electrical apparatus and of this the converter and transformer represents about one-half, and it can readily be appreciated that changing the voltage at the substation is a small part of the total cost.

There have been cases in the past where it was as simple to arrange substations originally designed for 600 volts and which contained two or more machines to provide for 1200-volt operation, merely by insulating the base of one machine and connecting the units in series; in fact some of the first 1200-volt roads in this country contain substation equipments arranged in this way. I would therefore suggest qualification of this statement.

In another sentence of this paragraph attention is called to the rectifier being able to withstand "instantaneous currents of even three times the normal value." It should be noted that standard, 500-kw., synchronous converters for railway service are guaranteed to stand three times normal load for one minute.

From this discussion it might be assumed that I oppose rectifiers as against synchronous converters, but such is not the case. Rectifiers are a comparatively new type of apparatus in this country, and their operation will be watched with interest, for undoubtedly there are applications where rectifiers are desirable. There are some points in Mr. Marti's paper, however, with which I cannot agree.

Albrecht Naeter (communicated after adjournment): Having had the privilege of making an acceptance test of one of the early Brown Boveri rectifiers in the United States, the writer was very much interested in this article by Mr. Marti, for he found that in the early stages of operation, after the forming period of the electrodes of the particular set tested, considerable difficulty was encountered by the operating staff in maintaining a good vacuum. Frequently only a few minutes after a vacuum determination had been made by the MacLeod type of gage the vacuum would drop quickly to a value considered unsafe for continued full-load operation. Fortunately the development of the novel electric hot-wire vacuum gage, according to the paper under discussion, has helped to ameliorate this situation because of the further researches made possible through it. The writer feels that, from the standpoint of the operating personnel, the vacuum-gage indication should be a continuously recording one that is visible at all times. Naturally this would be taken care of through the automatic feature of the vacuum-pump set in complete automatic sets, provided the rectifier is kept out of service without an operator's attention when the vacuum is low.

The writer recognizes the advantages of rectifiers, and agrees heartily with their use for higher voltages such as are common in railway work. It seems that undue stress has been laid upon the relative merits of these rectifiers and synchronous converters. Mr. Marti points out in his paper that the best field of application of these rectifiers is that of higher voltages,—higher than those of the commercially practicable synchronous converters. If the efficiency curves in Fig. 21 had been plotted for 240-volt machines, instead of 600-volt, and for the same kilowatt rating, the rectifier would probably have been found at a disadvantage. The rectifier would have shown up still less favorably if the overall efficiency of a 3000- or 4000-kw. synchronous-converter set of 240 volts had been compared to that of the several rectifiers required for the same output. A number of years ago the technical press was full of articles on the relative merits of motor-generator sets and synchronous converters, on the assumption that was then accepted that these machines were equally applicable to the same field; but now it is recognized that each has its particular advantages that make its application desirable in certain cases.

Inasmuch as the author places emphasis on the merits of rectifiers, it would have been well, for the sake of completeness of the article, to summarize some of the disadvantages of rectifiers, particularly as compared to the converter, (since he carries out that comparison), such as low efficiency at 240 volts, limited maximum sizes now available, lack of neutral for three-wire systems, etc.

O. K. Marti: Referring to Mr. Prince's remarks regarding engineering opinion concerning the design of various types of rectifiers, I should like only to call attention to the fact that the Brown Boveri rectifier, a cross-section of which is shown in my paper in Fig. 10, outnumbers the A. E. G. type shown by Mr. Prince, in the proportion of ten to one, and it can be inferred from this fact that the eventual development will probably result in a type similar to the one shown in Fig. 10 in my paper.

With reference to Mr. Shand's discussion, it was interesting for me to note that two companies have followed, independent of each other, practically the same lines in developing the steel-enclosed rectifier. Regarding the two systems of ignition, it is certain that the a-c. system of ignition and excitation is far superior to the other system, since it does not require an auxiliary d-c. generating device.

I am obliged to Mr. Shand for the additional references for my bibliography and, at this opportunity, I should also like to mention a series of articles by Dr. Schaefer, published in the BBC Mitteilungen, 1919, Nos, 3, 5, 7, 8, and 9; incidentally, these articles discussed for the first time a method of compounding mercury-arc rectifiers similar in principle to the one on which Mr. Prince's paper is based.

To Mr. Faron's remarks, I should like to add that, under normal operating conditions, a rectifier will not back-fire, but there is no question that back-fires may occur under abnormal conditions, such as those caused by inadmissibly high overloads, poor vacuum due to leakage or the use of improper material in the manufacture of the rectifier.

Regarding starting, I wish to bring out the fact that a rectifier can be started in less than two seconds, being then immediately able to pick up load. This surely is an advantage over a rotary converter which requires about thirty seconds for starting, and therefore cannot take care of any load before that time. To a railroad company, for instance, it means a great deal to have no delays of trains caused by lack of power.

Referring to the over-compound characteristics of traction conversion devices, it would have been interesting if Mr. Faron would have mentioned not only the fact that 90 per cent of the installed synchronous converters have over-compound characteristics, but would also have stated what was the percentage of converters with such a characteristic ordered during the last year. He would probably have found that it was about 50 per cent. This would have given a true picture of the status of the matter. Moreover, it would have been interesting if he would also have given the relative advantages of the two characteristics for railway service. I, personally, cannot see any, but will state here some of the many advantages of a drooping characteristic. It is realized by most railway men that the latter characteristic

guarantees a far more flexible operation and a far better distribution of load between neighboring substations. This results in a better load factor, allows giving the same service with a lower station capacity, reduces the losses in the feeders, and does away, in most cases, with a load-resisting device. This last means nothing else than a complication of the system and a great waste of power as long as it is in operation.

As to the floor space needed by a rectifier, it is true that the actual floor space required by a 600-volt rectifier, with all its auxiliaries, is somewhat more than for a rotary converter of the same voltage and capacity. However, considering the smaller weight of the rectifier, it is possible to utilize the space available for the converting units more effectively,—for instance, by mounting the rectifier and its auxiliaries on different floors of a building. Moreover, for the same reason, a lighter foundation, and also a lighter building construction, can be used, so that both in the erection of new buildings and in the adaptation of old buildings to substation uses, a material gain is effected.

With reference to the efficiency curves shown in Fig. 21A of my paper, I should like to mention that they were derived from data published by American manufacturers, including the stray losses according to the A. I. E. E. Standards, given as one per cent of the output. The efficiency of the transformers was taken to be the same for both the rotary converters and the mercury-arc rectifiers.

Regarding the automatic control, Mr. Faron states that auxiliaries will have to take care of abnormal conditions; but this holds true also for rotary converters. I wish to point out again that the automatic control of a rectifier is much simpler than that of a rotary converter, as most of the operations necessary in starting a rotary converter,—such as step-changing, raising and lowering the brushes, polarity check, etc.—are absent in the starting of rectifiers, for which the total starting operation consists of the natural sequence of closing the a-c. breaker, the automatic ignition, and closing the d-c. breaker. Due to the valve action of the arc, the protection which Mr. Faron recommends is not needed for the usual a-c. voltage supply.

I fully agree with Mr. Naeter's statements, and I think he is more than right when he compares with the present conditions the state in which electrical engineers were when the rotary converter came into prominence to take the place of the well established motor generator. There is no question but that a rotary converter will in many cases have an advantage over a mercury-arc rectifier, just as a motor-generator set shows outstanding advantages over the rotary converter in certain applications.

MOTOR VEHICLE LIGHTING TESTS

An interesting series of lighting tests were conducted in connection with the meeting of the joint Steering Committee of the Illuminating Engineering Society and the Society of Automotive Engineers which was held during the recent convention of the S. A. E. at French Lick.

Seven cars were equipped with special test head-lighting equipment consisting of two pairs of headlamps on each car giving a graduation of vertical and horizontal spreads of light over a wide range. Means were provided also for securing asymmetric distribution (low beam on the left and high beam on the right).

The demonstrations attracted considerable attention in that they showed the wide range available which could be made to conform to the state requirements while meeting the tastes of different car operators. A large number of persons participated and it is hoped that their comments will aid the committee materially in guiding future work.—From I. E. S. *Transaction*, July 1926.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

INSIDE-FROSTED LAMPS

A Discovery Promoting Efficient Light Production

Growing appreciation of the importance of good electric lighting during the decade between 1915 and 1925 led to much wider use of diffused light. Diffusion by enclosing the lamps in translucent glassware and adequate shades and by using other devices was a vague subject to the general public.

Consequently with the advent of the high-efficiency tungsten lamp, the manufacturers endeavored to conceal the bright filaments by etching or frosting the bulbs. Frosting on the outside of the bulb proved objectionable for two chief reasons. It was wasteful of light, offsetting, to a slight degree, the great progress made in increasing the light-producing efficiency of the filament. Also, outside-frosted lamps collected dust and dirt quickly, which could not easily be wiped off.

For many years lamp engineers realized that a lamp frosted on the inside, instead of on the outside, would be very desirable. It would not only present a smooth outside surface and be as easily cleaned as a clear lamp, but a lighter frosting would suffice, increasing the efficiency. The trouble with the idea was, that when a lamp bulb was frosted on the inside, it became as brittle as an egg shell. For twenty years engineers wrestled with this problem to no avail, until Marvin Pipkin, of the National Lamp Works of the General Electric Company solved the difficulty. The method is simple.

A strong solution of acid is first sprayed into the bulb, which etches it. In this condition the surface of the glass is made up of irregular little projections with many sharp angles. While the glass is still in this state it is extremely weak, and a slight pressure or bump is sufficient to shatter it. So far, the process is similar to former attempts at inside frosting. The difference lies in the strengthening process, which is the application of another acid solution, somewhat weaker than the first. This second treating rounds off the sharp edges and minute projections, giving the glass an appearance, under a powerful microscope, of being made up of tiny hemispheres. The bulb is now strong again,—just as strong as it was originally.

Superiority of the inside-frosted lamp over the outside-frosted, so far as light transmitting characteristics are concerned, also needs explanation. In the outside-frosted lamp, light from the filament travels through the gas or vacuum to the wall of the bulb, then through the glass, on the outer surface of which it meets the frost. Then, depending upon the direction of the plane of the particle of rough surfaces, the beam either passes on through the frosted surface as useful light or is reflected back through the glass layer. Each time the light passes through the glass, a certain amount of absorption takes place.

Diffusion of the light by the inside frost is obtained

by prismatic refraction with comparatively little loss. In fact, the inside frost allows an even greater portion of the light to pass through than does a similar frost on the outside of the lamp. This is due to the fact that the multiple internal reflections are not so numerous in the inside frosted lamp because the rough, interior surface does not reflect any considerable portion of the light back and forth inside the lamp, as happens with the outside-frosted lamp. Moreover, the relative absorption of the inside frost does not increase so rapidly with the life of the lamp as does that of other diffusing media.

For these reasons, then, the inside-frosted lamp is only about two per cent less efficient than a clear lamp, contrasted with a loss of efficiency of three to four times this much in the old style sand-frosted and sprayed lamps.

Another great benefit of the discovery of inside frosting is at once apparent when it is realized that now the manufacturers need only one type of lamp of each wattage instead of lamps with several different finishes. This is beneficial not only from the standpoint of economies resulting from the increased use of automatic machinery and the decreased investment in lamps lying idle in warehouses and on dealers' shelves, but also there is still greater benefit for the public in general. Since the inside-frosted lamps give practically as much light as clear lamps, they can be used to replace clear lamps for every ordinary use. This means that wherever, because of ignorance or carelessness, lamps are used without proper shades or glassware, the inside-frosted lamps will afford a certain degree of eyesight protection. Furthermore, wherever lamps are properly shaded, the inside frosting will eliminate sharp shadows and striations, with negligible loss of efficiency.

The invention of the inside-frosting process, of the same order of importance as the invention of gas-filled lamps and tipless lamp construction, is one more example of the value of systematic research, persistently pursued.

EUROPE ORGANIZES ITS LIGHTING ACTIVITIES

Within the last two or three years an increasingly greater amount of attention has been given in various European countries to the promotion of better lighting in factories, homes offices and the like. Lighting demonstrations, illumination courses, technical and advertising literature are all being pressed into service to carry the message of good lighting to the people of many foreign lands. A list of some of the European countries where this work is now being carried on intensively would include England, France, Germany, Italy, Austria, Sweden, Czechoslovakia, Belgium, Scotland and perhaps some others.

Holland has only recently organized an Illuminating Engineering Society which is supported by a number of able and prominent men.

Like some of the others, this new society has the following objects:

1. To educate the public in the art of illumination by lectures, demonstrations, publications and the like.
2. To demonstrate proper and practical ideas about lighting to pupils already in school.
3. To encourage the application of proper lighting in practise by giving information and advice to those who desire it.
4. To bring about new applications and improvements in lighting through the standardization of accessories and development work.

It is being organized to accomplish these things by means of permanent demonstration rooms, illuminating engineering and general educational service.

A lecture given by Mr. C. P. Jensen before the thirty-first Congress of the V. D. E. (Association of German Electrical Engineers) in June, at Wiesbaden dealt with the German Society of Lighting Economics from the point of view of the electrical organizations in Germany. It was a plea to them to unite in a cooperative movement for a broader understanding of lighting economics as a means of rendering a greater service to the users of light.

Once a suitable neutral basis for the cooperation of the electrotechnical industry has been created in the field of illuminating economics, there remains only the question of its practical influence on the broad masses of the light-consuming public with the view to increasing the service of this great electric lighting industry.

It is hoped that a growing demand for electric lighting service will be established and that through increased production and other advantages to be derived from better lighting, a great economic good will be accomplished.

Europe today, says Mr. Jensen, is setting out on a program of electrical standardization similiar to that which has meant so much to electrical progress in America. Plans are being made to standardize the voltages of lighting circuits and to decrease the number of lamp types.

These German activities received their impetus over a year ago with the opening at Berlin of the new "house of light" containing a group of lighting demonstration rooms. Since then some 50,000 people have been initiated there into the "mysteries" of good lighting. Furthermore, many well attended illumination courses have been given and these have helped to spread the idea of the advantages of better lighting.

TREND OF ELECTRIC LIGHTING

Significant are many of the trends shown in the annual report of the National Electric Light Association's Lamp Committee. In three years the average wattage of lamps consumed has risen from 55.6 to 57.6; the percentage of exactly 115-volt lamps has risen from 42.8 to 44.6. The Committee recommends that every member company have a "well organized Lighting Service Department," and that there be permanent lighting demonstration rooms in every city of the country.

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Pacific Coast Convention

SALT LAKE CITY, SEPTEMBER 6-10, 1926

"Excellent from a professional standpoint and highly enjoyable socially" was the verdict rendered, by the two hundred and fifty or more members and guests in attendance, upon the Annual Pacific Coast Convention held at the Hotel Utah, Salt Lake City, September 6-10.

The technical program included numerous high-grade papers covering a wide variety of topics, discussions contributed by members and guests were valuable, inspection trips to power plants and other places of engineering interest were well managed, and all the visitors were highly appreciative of the cordial hospitality extended by the Salt Lake City members and the ladies of their families.

Student Activities

The first event of the Convention was a Conference of Counselors and Student Branch Chairmen of the Pacific and North West Districts, on Monday morning, September 6. The Counselors present were: Henry H. Henline, Stanford University; J. Hugo Johnson, University of Idaho; T. C. McFarland, University of California; J. F. Merrill, University of Utah; F. O. McMillan, Oregon Agricultural College; S. G. Palmer, University of Nevada; George S. Smith, University of Washington; Royal W. Sorensen, California Institute of Technology; and J. A. Thaler, Montana State College.

The Student Chairmen present were: F. D. Crowther, Oregon Agricultural College; J. W. Cruse, University of Arizona; Chas. F. Dalziel, University of California; Thomas L. Gottier, California Institute of Technology; Clarence M. Murray, Jr., University of Washington; and Alfred V. Pering, Stanford University.

President Chesney, National Secretary Hutchinson, Vice-President Schoolfield and others interested were also in attendance.

Professor Merrill was elected Chairman of the Conference, and Professor Smith Secretary. There was an interesting and profitable discussion regarding various student activities and recommendations were adopted which will be transmitted to the Board of Directors.

Later in the week the Counselors of each of the two Districts met separately and organized as Committees on Student Activities for their respective Geographical Districts as follows:

Pacific District Committee: Chairman, Professor H. H. Henline, Stanford University; Secretary: Professor R. W. Sorensen, California Institute of Technology.

North West District Committee: Chairman: Professor J. A. Thaler, Montana State College; Secretary: Professor George S. Smith, University of Washington.

Opening Session

The first technical session was held on Monday afternoon and was called to order by Mr. C. R. Higson, Chairman of the Convention Committee, who greeted the members and guests and then presented George H. Dern, Governor of Utah, who delivered an excellent address of welcome. Chairman Higson then presented President Chesney as the presiding officer of the Convention, who in responding, congratulated the people of Utah upon having elected an engineer to the office of Governor.

President Chesney then delivered a brief address relating principally to research and standardization, in which he outlined certain major policies which he believed should be followed by the Institute.

He mentioned as examples of leaders in the research and development work in the electrical engineering field in this country, William Stanley, Nikola Tesla, Benjamin Lamme, and Chas. P. Steinmetz, giving a brief outline in each case of the contributions of these leaders. After reviewing briefly the work done upon standardization in the electrical field in this country, President Chesney continuing said:

"The American Institute of Electrical Engineers for the past twenty-five years, through its Standards Committee, has taken the initiative in the formulation of all the electrical standards of America, and its work is recognized as being authoritative throughout the entire world. Its procedure and its resulting standards during this period have been acceptable to the manufacturing and the consuming interests as well as to the general public. The industry has learned to value and depend upon the A. I. E. E. standards in commercial transactions covering matters of interest to all sections of the electrical industry. It has made no attempt to dictate to industry, but introduces standards on any particular line only when it is clear that all interested parties agree that the step is wise and desirable.

"In the Institute Standards Committee, or in its subcommittees, the manufacturer and purchaser and the general interests come together and develop the required standards in a way which has been generally satisfactory to all the interested sections of the industry. The electrical standards so issued have been identified with the name of the Institute, and its name should be continued in connection with them, and in the interest of simplicity and order it would appear that no other name was necessary. It should be remembered that the Institute as an organization has no interest other than one of public service, which duty the Institute has performed throughout the entire period of twenty-five years at its own expense. The Institute, therefore, in connection with the voluntary formulation of electrical standards, has assumed obligations during the past quarter of a century to the electrical industry and to the public which make it now impossible to discontinue the

present practise or lessen its responsibilities until a more simple and direct method has been devised and demonstrated."

The following papers and discussions were then presented:

The Space Charge that Surrounds a Conductor in Corona, by H. J. Ryan and J. S. Carroll, Stanford University. (Presented by Professor Carroll.) Discussion by Messrs. Harris J. Ryan, H. E. Mendenhall, F. O. McMillan and J. S. Carroll.

110-Kv. Transmission Line Construction of the Washington Water Power Co., by L. R. Gamble, Washington Water Power Co. (Presented by the author.) Discussion by Messrs. C. R. Higson, Harold Michener and the author.

A New 220-Kv. Transmission Line, by C. B. Carlson and H. Michener, Southern California Edison Co. (Presented by H. Michener.)

Effect of Unbalanced Tension in a Long-Span Transmission Line, by E. S. Healy and A. J. Wright, Electric Bond and Share Co. (Presented with lantern slides by Mr. Healy.) Discussion by Harold Michener.

Tuesday's Technical Session

The technical session on Tuesday morning was presided over by Vice-President Paul M. Downing, of San Francisco. The following papers were presented:

The Circle Diagram of a Transmission Network, by F. E. Terman, Stanford University. (Presented by the author.)

Calibration of Lichtenberg Figures, by K. B. McEachron, General Electric Company. (Presented by the author.) Discussion on the above two papers was presented by Messrs. J. Slepian and K. B. McEachron.

Stability Characteristics of Alternators, by O. E. Shirley, General Electric Company. (Presented by the author.)

Synchronizing Power in Synchronous Machines, by H. V. Putnam, Westinghouse Electric & Manufacturing Co. (Presented by the author.) Discussions followed by Messrs. David Hall, C. A. Nickle, F. E. Terman, H. V. Putnam, and O. E. Shirley.

At the afternoon session, Vice-President Downing presiding, the following papers were presented:

Vacuum-Switching Experiments at California Institute of Technology, by R. W. Sorensen and H. E. Mendenhall, California Institute of Technology. (Presented by R. W. Sorensen.) Discussion by Messrs. J. Slepian, D. C. Prince, H. E. Mendenhall and R. W. Sorensen.

Electrical Practise in Lead-Silver Mines in Utah, by Leonard Wilson, Consulting Engineer. (Presented by the author.)

Electricity and Coal Mining, by Daniel Harrington, Chief Safety Engineer, U. S. Bureau of Mines. (Presented by Mr. H. T. Plumb.) Discussion by Messrs. Paul Ransom, H. T. Plumb, D. C. McKeehan and Paul M. Downing; also a communication from F. L. Stone.

Engineering Education: Its History and Prospects, by H. H. Henline, Stanford University. (Presented by the author.) Discussion by Messrs. F. E. Terman, J. H. Johnson, George H. Smith, R. W. Sorensen, D. I. Cone, H. T. Plumb, D. C. Prince, H. Michener, K. B. Miller, F. O. McMillan, G. Ross Henninger, David Hall, Paul M. Downing and H. H. Henline; also a written discussion from L. R. Robinson.

Wednesday's Technical Session

Vice-President H. H. Schoolfield, of Portland, Oregon, presided at the session on Wednesday morning, and the following papers were presented:

Protection of Oil Tanks against Lightning, by F. W. Peek, Jr., General Electric Company. (Presented with motion pictures by the author.)

Fire Protection of A-C. Generators, by J. A. Johnson, Niagara Falls Power Co., and E. J. Burnham, General Electric Company. (Presented with lantern slides by E. J. Burnham.) Discussion on the above two papers was presented by Messrs. J. Slepian, R. W. Sorensen, D. I. Cone, B. F. Howard and F. W. Peek, Jr., and a written discussion from E. H. Freiburghouse.

Thursday's Technical Session

At the final technical session on Thursday morning, Vice-President Schoolfield presiding, the following papers were presented;

Variable Voltage Equipment for Electric Power Shovels, by R. W. McNeil, Westinghouse Electric & Manufacturing Co. (Presented by the author.) A written discussion was presented from R. S. Stevens.

Temperature of a Contact and Related Current-Interruption Problems, by Joseph Slepian, Westinghouse Electric & Manufacturing Co. (Presented by the author.)

Transcontinental Telephony, by O. B. Jacobs and H. H. Nance, American Telephone and Telegraph Co. (Presented by O. B. Jacobs.)

Controlling Insulation Difficulties in the Vicinity of Great Salt Lake, by B. F. Howard, Mountain States Telephone & Telegraph Co. (Presented with lantern slides by the author.) Discussion by Messrs. J. B. Johnson, K. B. Miller, A. S. Peters, W. C. Lee and B. F. Howard.

Carrier-Current Communication on Submarine Cables, by H. W. Hitchcock, Pacific Telephone and Telegraph Co. (Presented by the author.) Discussion by Messrs. J. E. Heller, K. B. Miller, and W. G. Rubel.

Entertainment Features

On Monday afternoon, practically all the members and guests in attendance participated in an excursion to the Saltair resort on the shores of the Great Salt Lake, where many enjoyed the unique experience of bathing in the lake which is noted for its great buoyancy. Dinner and dancing occupied the time of the visitors until a late hour.

The principal social event of the Convention occurred on Wednesday evening, at which time all the members and guests present attended a dinner in the Hotel Utah, at the conclusion of which greetings were extended by C. R. Higson, Chairman of the Convention Committee, who then presented President Chesney as the presiding officer of the evening. Distinguished guests present included Senator Reed Smoot, Mayor C. Clarence Neslen of Salt Lake City, and President Grant of the Church of the Latter Day Saints. A brief and exceedingly interesting address was delivered by Senator Smoot, after which followed the ceremonies in connection with the presentation of the Edison Medal to Dr. Harris J. Ryan, as described more fully elsewhere in this issue. During the dinner the guests were favored with music and singing by local talent.

The program of the week included many other enjoyable events, beginning with an organ recital in the celebrated Mormon Tabernacle at noon on Monday. There were various drives about the city and nearby canyons for the ladies, including luncheon at the Country Club on Tuesday, and at the Pinecrest Inn, at the head of Emigration Canyon, on Wednesday.

One of the principal events was an informal reception on Tuesday evening, the receiving line consisting of President and Mrs. Chesney, Dr. and Mrs. Harris J. Ryan, Vice-President and Mrs. Paul M. Downing, Vice President H. H. Schoolfield, National Secretary F. L. Hutchinson, Mr. and Mrs. C. R. Higson, Mr. and Mrs. B. C. J. Wheatlake, and Mr. and Mrs. H. T. Plumb. Following the reception, a highly interesting, illustrated lecture on Western Canyon Scenery was given by Randall L. Jones, after which dancing completed the evening's entertainment.

A Golf Tournament was conducted on Wednesday afternoon, the winners being Vice-President Paul M. Downing and the runner-up, P. A. Parry, of Salt Lake City. Prizes were presented to the winners by Chairman Wheatlake of the Utah Section at the closing Convention session. By winning the tournament, Vice-President Downing became the custodian of the John B. Fisken Cup, which is competed for each year at the Pacific Coast Convention.

Upon the adjournment of the final session on Thursday noon,

the members and guests were taken by busses for an excursion to Bingham Canyon and Magna, visiting the famous Mine and Mills of the Utah Copper Company, where the operations, including blasting, were of great interest to the visitors. A visit was also made to the underground workings of the Utah-Apex Mine.

On Friday there was an all-day excursion provided by the Utah Power and Light Company to the Company's new hydro-electric station at Cutler on the lower Bear River.

During the Convention, a Conference was held of the Vice-Presidents of the Pacific and North West Districts and the representatives of the Sections within those Districts, at which it was decided to recommend that next year's Pacific Coast Convention be held in the San Francisco territory at a date to be determined later.

In addition to the various scheduled events referred to above, there were many courtesies extended by the local members and ladies of their families. A Local Ladies' Committee, which was particularly active in providing for the comfort and pleasure of the visiting ladies, consisted of Mesdames Brundige, Clark, Hale, Higson, Moser, Plumb, Rowley, Salberg and Wheatlake.

At the final session of the Convention, a motion was adopted expressing the high appreciation of the visiting members and guests of the effective services of the Local Convention Committee in making and carrying out with gratifying success the plans for the various events of the Convention. The local members were: Messrs. C. R. Higson, Chairman, P. P. Ashworth, H. G. Baker, D. L. Brundige, H. W. Clark, R. J. Corfield, C. P. Kahler, J. A. Kahn, C. A. Malinowski, J. F. Merrill, H. T. Plumb, C. C. Pratt, Paul Ransom, John Salberg, M. M. Steck, H. B. Waters, and B. C. J. Wheatlake.

Edison Medal Presented to Harris J. Ryan

The most impressive feature of the Pacific Coast Convention was the presentation of the Edison Medal to Dr. Harris J. Ryan at the dinner on Wednesday evening, September 8, 1926.

President Chesney presided and announced that the members and guests were assembled to honor Harris J. Ryan, Past President of the Institute, to whom the Edison Medal for the year 1925 had been awarded. He then called upon National Secretary Hutchinson, who briefly outlined the origin and significance of the Edison Medal.

President Chesney then called upon Vice President Paul M. Downing, of San Francisco, who spoke of the work and achievements of Dr. Ryan, in part as follows:

We are here this evening to do honor to one whom we all respect, admire and love, a man whose accomplishments in the field of scientific research and engineering have pointed him out as one upon whom the American Institute of Electrical Engineers should confer this particular mark of distinction. To those of us from the far west this is a particularly happy occasion because for more than 20 years we have had the pleasure and the proud privilege of claiming Dr. Ryan and his charming wife as residents of our sunny state of California.

Born in Powell Valley, Pennsylvania, Dr. Ryan received his early education in Baltimore City College and Lebanon Valley College. Leaving the latter he entered Cornell in 1883, about the time that institution was inaugurating its electrical engineering course. After graduating from Cornell in 1887 he was for 2 years associated with J. G. White and D. C. Jackson then engaged in general engineering practise under the firm name of Western Engineering Company. In 1889 he returned to Cornell as instructor in charge of the electrical machinery laboratory. This change marked the turning point in his career in that he left the field of commercial engineering to enter that of scientific research. Advancement in his chosen line of work was rapid. In 1890 he was made assistant professor in electrical engineering at Cornell and in 1895, when only 29 years of age, he was honored by being appointed as professor in full charge of the electrical engineering department. He remained in that position until 1905 when the "kid" professor as he was then known accepted the call of Stanford University to take charge of the electrical engineering department of that institution, which position he still holds.

In reviewing Dr. Ryan's accomplishments one cannot help but be impressed by the clear foresight and unprejudiced manner in which he has approached every problem confronting him. Scientific investigation is by its very nature pioneer work. It differs from that of engineering in that the scientist must work away out in advance of the engineer. He must point out the way by blazing a trail along which the latter may follow perhaps years later and put to practical application the fundamentals that have been established by the scientist. It therefore follows that if a man is to be successful in scientific research work he must love his work, he must be a man of broad imagination, and he must have unlimited enthusiasm. Dr. Ryan answers all of these specifications.

Since 1889, Dr. Ryan has been a liberal contributor to technical literature, many of his papers having been presented before this Institute. In reviewing his work one cannot help but be impressed with the fact that unlike many others engaged on more or less highly technical research work, Dr. Ryan has devoted his time and attention very largely to the scientific study of problems that have great practical and economic value to the electrical industry. As substantial evidence of this we find that one of his earliest contributions to electrical progress was a paper describing the development and pointing out the advantages of using balancing coils, as they were then termed, designed to overcome field distortion and the shifting of the neutral point in direct-current machines, due to armature reactions. The first practical application of this principle was in the Thompson-Ryan generator which was the forerunner of the present day interpole type of construction now used almost universally in direct-current generators and motors. This one improvement alone has been of tremendous commercial value to the industry not only in the improved operation of d-c. equipment, but by its application, the size and weight of machines per unit of capacity has been materially reduced, thus reducing the price correspondingly.

But important as his studies in the field of direct current have been, those having to do with alternating current are of even greater importance. Looking back from our present position to the early 90's, it seems easy in the light of present day knowledge to imagine how a high voltage system might very easily have been brought into existence, but at that time the scientific world knew but little about alternating currents and less about high voltages. There were wide differences of opinion respecting the possibilities of developing and transmitting power over long distances and there were wider differences of opinion on the question of whether alternating current or direct current was best suited for transmission purposes.

It was in the laboratory at Cornell University that Professor Ryan began his studies in connection with the use of high voltages. Suitable equipment and facilities for carrying on his investigations were not available. Much of what he needed had to be built in the laboratory under his direction. Even at that time, when so little was known about high voltages, his foresight and wisdom in determining what the design and construction of such equipment should be were sound and it is interesting to know that the 90,000-volt dry insulated transformer built by him many years ago is still in service and is an important part of the Cornell laboratory equipment.

His paper on transformers presented before the institute in 1889 is one of his outstanding accomplishments. It was received by the scientific world with an enthusiasm that immediately brought the author into the limelight of international fame.

No small part of the success attending the investigations covered by this paper is due to the development of the cathode ray wave indicator, or as it is now generally called the cathode ray oscillograph. Its development was more or less of an incident in connection with the solution of the bigger and more important problem being studied but it proved to be a most important factor in obtaining results that otherwise might not have been possible. It not only served a most useful purpose in connection with the work then in hand but during recent years it has found a broad field of usefulness in studying the high frequencies used in connection with the transmission of the human voice.

A few years after this paper was presented certain experiments conducted on certain lines operating in the Rocky Mountain region resulted in the announcement by transmission engineers that 40,000 volts was the limit for transmission lines and it was useless to attempt to go higher. Doubting the truth of this announcement, Dr. Ryan with a pioneer spirit born of that type of mind to which all attainment is but a challenge to further effort, definitely determined to prove that the use of much higher voltages was not only possible but entirely practical. His investigations and studies along this line continued until 1904 when he summarized the results in a paper presented before the Institute entitled, "The Conductivity of the Atmosphere at High Voltages." The fundamentals set forth in this paper were a distinct contribution to electrical science. By establishing the law of corona formation the problem of transmitting power at high voltage was materially simplified and the former theory that 40,000 volts was a maximum beyond which it was impractical or impossible to go was completely disproved.

During recent years Dr. Ryan has devoted a great deal of his time and attention to the study of insulation and insulators for use on high voltage lines. The results of his investigations covering the distribution of voltage across the different units making up a string of insulators and the best manner of equalizing same, the cause and effect of aging of porcelain, the causes of failures and flashovers of insulators and other similar work have been of inestimable value to the engineering fraternity in the design and successful operation of present day high-voltage lines. As a result of these investigations, insulator manufacturers have been able to improve the design and quality of their product to a point where today we find 220,000-volt transmission lines operating more satisfactorily in every respect than do those of lower voltages constructed at times when we knew less about insulators and insulation than we do now.

No one will question the fact that during the past 30 years, transmission

of electric power has been one of the very great, if not the greatest, factors contributing to the growth of material wealth and the relief of labor. That growth has been made possible in a very large measure by the splendid work that has been done and is today being done by Dr. Ryan and others in working out the highly complicated problems that have confronted the industry without the solution of which progress would have been greatly retarded.

In recognition of the importance and value of the work that has been done and as substantial indication of their desire to have it continue, a number of electrical companies, both manufacturing and central station, have contributed toward the establishment of a modern up-to-date high tension laboratory at the University where research work well in advance of the industry can be carried on. As a compliment to our honored past president and co-worker, this new laboratory, known as the Harris J. Ryan High Tension Laboratory, will forever stand a splendid monument to the untiring energy and ability of the man whose name it bears. So far as funds will permit the laboratory is well along toward completion but it is not yet fully equipped.

That the electrical industry is willing to recognize and accept its indebtedness to Dr. Ryan and the University, not only on account of the splendid work that has already been done but also on account of the broad liberal policy concerning future work, is evidenced by the generosity of the donors without whose financial assistance and support the ideals of Dr. Ryan and his co-workers could not have been realized.

But beyond all of his accomplishments in the field of scientific work we must not overlook other of his achievements that can be measured only in terms of human value. During the more than 30 years that Dr. Ryan has devoted to training the minds and habits of young men he has endeared himself to all with whom he has come in contact and in this brief resumé of Dr. Ryan's achievements as a scientist and a teacher, I could not properly conclude without paying a tribute to Mrs. Ryan. Along with Dr. Ryan she has always taken a parental interest in the work and welfare of their students. Their home has always been open and students have always been received with a hearty welcome.

At the conclusion of Mr. Downing's address, President Chesney presented the Medal and Certificate of Award to Dr. Ryan, who in response spoke in part as follows:

I appreciate profoundly the award of the Edison Medal and the opportunity that I have now had of receiving the certificate of award and the medal from the hands of those who have been my life-long friends and virtual co-workers functioning as the officers of the Institute.

At this extraordinary moment in my life my mind goes back to the beautiful and inspiring resolution that the Edison Medal Association made a part of its deed of trust to the American Institute of Electrical Engineers for the award of the Edison Medal which reads:

WHEREAS: it seems to the (Edison Medal) Association that the most effective means of accomplishing the object for which it was formed would be the establishment of an Edison Medal which should, during the centuries to come, serve as an honorable incentive to scientists, engineers, and artisans to obtain by their works the high standard of accomplishment set by the illustrious man whose name and features shall live while human intelligence continues to inhabit the world.

Its full significance will be born in upon us when we remember the things of incalcuable value in the world today that would be absent had there been no Edison. No man ever lived to be a finer example of the glory of work for the amelioration of the conditions under which mankind must live and be happy.

The Certificate of Award and the Edison Medal are received by me in a deep consciousness of their significance and most earnestly do I hope that I may continue to deserve them as long as life shall last.

It is eminently proper when a man has been awarded the Edison Medal by the American Institute of Electrical Engineers that he should be called upon to give an account of himself and that I now gladly do.

Forty-three years ago this fall I entered Cornell as a freshman to take up the curriculum in electrical engineering, that had just been established and for which students were being admitted for the first time. The electrical engineering laboratory of the University was little more than the electrical section of the Physics laboratory of that day. The little more just referred to was one direct-current generator invariably referred to as the Gramme dynamo that was built by Professor Wm. A. Anthony, the 1890-1 President of the Institute.

Professor Anthony visited France immediately after 1872 when Gramme had completed his direct-current generator, generally conceded to have been the first direct-current dynamo of an ample size to reveal its possibilities in the engineering industries. Professor Anthony visited Gramme, saw his generator, and on returning to Cornell immediately set about to construct a replica thereof. It was completed in 1874 and exhibited just a half century ago at the Centennial in Philadelphia. Curricula in electrical engineering at Columbia, Cornell and other universities were announced somewhat less than ten years after the Centennial.

Anthony's Gramme dynamo was given at Philadelphia an award of merit for its novelty and enterprise. It was placed in the historical exhibit at the Chicago International Exposition only 17 years later, and was given an award for its historical merit. I was a member of another section of the Chicago World's Fair jury and had nothing to do with the award of historical merit for "Anthony's Old Gramme." However, I shall never forget the deep impression that the award made upon me. Even then after only 17 years of progress in our country the dynamo had become one of the great implements of our civilization. The lesson of the extraordinary progress that the electrical sciences and arts were making, was inescapable.

I had up to the time of the Paris Exposition in 1889 encountered the then traditional attitude of mind that dwelt much upon the historical background of things from out of which one looked with anticipation of few out-and-out new expediencies and implements arriving at a slow rate as always.

But the extraordinary personal exhibit of Edison at the Paris Exposition of 1889 began to change all that sort of thing for me as it did for a host of others of my generation and the Chicago 1893 award to Anthony's Old Gramme finished the change of mind for me, as I know it must have for many others. From that time to this I have belonged to the group that with all the persistence and enthusiasm its individuals can muster has held steadily to the purpose of finding out about things from the depths of the unknown; of opening up new seams in the face of the rock that must be penetrated to know what is within and beyond.

Attitude of mind is an enormous factor of human progress—and progress there must be, so long as human beings will hold the option of changing this old world from what it is to what it ought to be.

In the fourth year of the Institute I began my work as a faculty man at my alma mater. I soon found the real meaning and value of the American Institute of Electrical Engineers to all in the electrical arts and sciences. I found that I was wholly unprepared to assist my students effectively to an understanding of things without end, encountered everywhere; particularly was this so as matters stood in that day, for the transformer in the alternating-current circuit and the armature reaction effects in the continuous current machine. The alternating-current system for economic incandescent lighting so well suited for the needs of the new rapidly growing American towns and cities had been introduced three years before, *i. e.*, in 1885-6 and its use was being extended rapidly.

With the aid of a friend of my student days, Ernest Merritt, past-president of the American Physical Society, I worked through the summer of 1889 upon the problem by systematic measurement upon a particular transformer in sufficient detail to meet our requirements for teaching. The work was done at Buffalo, New York, through the courtesy of C. R. Huntly, Executive, and H. H. Humphreys, Engineer, of a lighting company of that city. We selected for our specimen a 10-light, 2000/50-volt, 133-cycle transformer.

Through Dr. E. L. Nichols, past-president of the Institute, I was invited to present a paper based upon our work on the transformer and the results obtained. The paper was duly prepared and presented at the December, 1889, meeting of the Institute in New York City and was published in the Proceedings in January, 1890. Then to me the entirely unexpected thing happened. The paper interested most of the trained workers in the electrical industries everywhere. It was republished seventeen times in America and Europe including Russia. From that time to this I have had friends everywhere throughout the electrical and related industries who have always wished me well and were ready with their helpful cooperation at all times. It was to me in relation to the Institute a wonderful lesson in many ways, particularly in two:

I. The value of getting at the facts singly and in their aggregate relation concerning phenomena and equipments for which uses are being found in the industries.

II. The extraordinary value of the American Institute of Electrical Engineers to its individual members and the electrical industries they promulgate.

The direct-current dynamo was put forward by the Italian Paccinoti in 1864 and first developed for engineering duty as already stated by the Frenchman, Gramme, in 1872. Like every great implement upon which our civilization is today established and maintained, the direct-current dynamo arrived as a product of the minds and industry of Paccinoti and Gramme complete in a sense and highly useful, but little understood as to details and as to their relation to the aggregate result. The lack of adequate knowledge of such details individually and collectively was a great handicap in education and for the progress of the art. To understand this one needs only to go back to the many distortions of the rational forms of continuous current machines that were put forward in many illusory efforts to make improvements nearly forty years ago.

With the aid of my students we began in 1892 a series of studies of commutation and characteristic behavior in relation to the shape of poles, length of air-gap and related factors. The results clearly indicated the helpfulness of the pole-face winding and commutating pole as they are now known. We were not the only persons to discern these helpful results, though we did enjoy with others the privilege of pioneering in these things. The final approach to perfection of the continuous current machine was not feasible in "the late nineties." That approach has been quite dependent upon the arrival of a good working understanding of polyphase current circuits.

The continuous current machine in recent years has rounded out its first great cycle of development. When, in America, it will enter upon its obvious second cycle, or better, its second round on its spiral of evolution, cannot today be foreseen. It is assuredly worth while for some engineers to remember always the wealth of expediency now available for such second round of evolution of this form of generator or motor. Should long distance transmission of power ever demand the use of the constant continuous

current generator and motor, there will be found a veritable mine of discernible expediency for evolving its success.

A third of a century ago from a faculty man's point of view, that of helpfulness to his students, I began the study of high voltage phenomena by constructing an oil immersed 30,000-volt transformer. The first decisive experimental result with it was soon obtained. It "burned out", but why, one could not tell. The most significant thing about the tragedy was a large smoke bubble that came to the surface of the dark heavy oil that was generally used at this time for insulating transformers. That was in 1893. During the following year we rebuilt it, using air in lieu of oil for immersion so that if it burnt out again we could see the fire and perhaps learn something of the cause. We kept the same core and coils and rebuilt the transformer the sixth time in 1899, air immersed and to have an output of 10 kw. at 90,000 volts, 133 cycles. The major insulation between the high and low voltage circuits was made by the Corning, New York, Glass Works of refractory glass. Each of the 30 high voltage coils was equipped with a 6000-volt non-arcing spark arrester. After that the transformer rendered satisfactory service at my alma mater through many years. It is a trivial incident in the telling but it made a real beginning for me as a high voltage worker.

In 1897 we learned through the pioneer high voltage studies of past Presidents Chas. F. Scott and Ralph D. Mershon, that at 40,000 volts, more or less dependent upon a variety of obscure factors, the electric current would escape into the atmosphere and a serious waste of power would in consequence occur.

The success of the long distance transmissions of power in the far west and from Niagara Falls to Buffalo caused a large division of the electrical engineers to set out upon the route that led to the establishment of the modern power industry. This division was directed on the right and left by the economic guidance of Kelvin and Sprague. The former asserted that the transmission of power is accomplished most economically when the existence and lost costs of the transmission conductor are equal. The latter asserted that economy in electrical power transmission varied directly as the voltage and inversely as the distance.

The discovery of Scott and Mershon that at a comparatively low voltage electric power would escape from the power transmission line sent a strong mental shock to this power division. As a faculty man greatly interested in the welfare of students preparing for service in the power division, I felt the shock keenly. For the cause of those students there was but one thing to do and that was to get at all the material facts as quickly as possible and then to study them for strategy in action. By February 1904, we had some of the facts and their relations well enough in hand to present a paper to the Institute that was received everywhere by the power division in such a whole-hearted manner of appreciation that I could not do otherwise than hope to have the privilege of being its permanent recruit.

I must interrupt this narrative in regard to my contacts as a faculty man with those who are establishing the power industry to say that through brief but highly appreciated years I have seen and enjoyed detached services in the large division of communication. In so doing I cooperated with those of my students who established the arc converter system of continuous wave radio telegraphy at home and abroad. My war work in the Supersonica Laboratory of the National Research Council, the purpose of which was aid of the allies in the perfection of the echo method for submarine defence, netted an experience in mechanical radio that has been highly valuable because of the many uses I have found for the same in my work with students. Thus it has been that I have learned abundantly in both the power and communication divisions of the electrical industries how enormously welcome a faculty man is to ask the privilege of camaraderie if he will but play the game right-mindedly. He must remember that he is a faculty man at all times and see to it that he is acting as such and that he is not acting to replace an engineer on the firing line of practise.

Dr. Ryan then showed some interesting lantern views of the new 2,000,000-volt laboratory at Stanford University, where further high voltage researches will be conducted.

The ceremonies ended with a brief address by Mr. H. T. Plum concluding with the following sentiment addressed to Dr. Ryan: "For your achievements as teacher, engineer and scientist, WE HONOR YOU! For your sincerity, devotion, humility and service, WE LOVE YOU!"

Regional Meeting in New York

NOVEMBER 11, 12, 1926

The two-day regional meeting to be held in New York City on November 11 and 12 will have three very instructive technical sessions and other features of much interest. The technical papers will cover the subjects of a-c. distribution networks, illumination and communication. There will be a lecture by a well-known speaker on the evening of November 11. A number of inspection trips are arranged for the afternoon of the same day. In order to allow for informal association of members, buffet luncheons will be held if possible on each day of the meeting. Also, a dinner is being planned for Thursday, November 11.

Headquarters for the meeting will be Engineering Societies Building, 33 West 39th Street, New York, where all events will be held with the exception of the dinner.

Further announcements will be mailed to all members in territory surrounding New York. It is urged that all who will attend notify Institute headquarters in advance by means of the card which will accompany the announcement in order that estimates may be made of the attendance, particularly at the luncheons and the dinner.

The following tentative program will give the general information on the meeting, though it is possible that some changes will be made later.

The general committee in charge of the meeting is as follows: H. A. Kidder, Chairman; O. B. Blackwell, H. V. Bozell, W. A. Del Mar, G. L. Knight, E. B. Meyer and G. H. Stickney.

TENTATIVE PROGRAM OF NEW YORK REGIONAL MEETING NOVEMBER 11 AND 12, 1926

THURSDAY MORNING—DISTRIBUTION SESSION

Recent Progress in Distribution Practise, J. F. Fairman and R. C. Rifenburg, Brooklyn Edison Company.

Combined Light and Power Systems for A-C. Secondary Networks, H. Richter, Westinghouse Electric & Mfg. Co.

Evolution of the Automatic Network Relay, J. S. Parsons, Westinghouse Electric & Mfg. Co.

Operating Requirements of the Automatic Network Relay, W. R. Bullard, Electric Bond & Share Company.

A-C. Network Relay Characteristics, D. K. Blake, General Electric Company.

THURSDAY NOON

Buffet Luncheon.

THURSDAY AFTERNOON

Inspection Trips.

THURSDAY EVENING

Dinner

Lecture by Prominent Scientist.

FRIDAY MORNING—ILLUMINATION SESSION

Remote Control of Multiple Street-Lighting Systems, W. S. Dempsey, New York Edison Company.

Lighting of Railway Classification Yards, G. T. Johnson, New York, New Haven & Hartford R. R.

The Induction Lamp, A New Source of Visible and Ultra Violet Radiation, T. E. Foulke, Cooper-Hewitt Electric Company.

FRIDAY NOON

Buffet Luncheon.

FRIDAY AFTERNOON—COMMUNICATION SESSION

Frequency Measurements with the Cathode-Ray Oscillograph, F. J. Rasmussen, Bell Telephone Laboratories, Inc.

A Shielded Bridge for Inductive-Impedance Measurements, W. J. Shackelton, Bell Telephone Laboratories, Inc.

Radio Broadcast Coverage of City Areas, L. S. Espenschied, American Telephone and Telegraph Company.

New York Section Meeting October 8

LECTURE ON FLAMES OF ATOMIC HYDROGEN

On the evening of Friday, October 8, 1926, the members of the New York Section will have the pleasure of hearing Dr. Irving Langmuir of the Research Laboratories, General Electric Company, describe "Atomic Hydrogen Arc Welding," recently developed by him. Dr. Langmuir's work, originating some fifteen years ago in a theoretical investigation of the heat loss of tungsten filaments of incandescent lamps in a hydrogen atmosphere, has now been applied in a different field—the development of a new method of welding. In brief, a stream of hydrogen is passed between two electrodes, the heat of the arc breaking up the hydrogen molecules into atoms. These combine again a short distance in front of the arc with the liberation of an enor-

mous amount of heat. Much higher temperatures are obtained than with usual welding methods and welding can be accomplished without oxidation and without fluxes. Dr. Langmuir's talk will be illustrated by extremely interesting slides and motion pictures.

The meeting will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York, N. Y., at 8.15 p. m. on October 8, 1926. A cordial invitation to attend is extended by the New York Section to all interested in the subject.

New York Electrical Society's First Meeting to be on "The Vitaphone"

On the evening of Wednesday, October 27, 1926, the New York Electrical Society will hold the first meeting of the year 1926-27. In line with the practise of the society to give to engineers and to the public reliable information on the most recent developments in the engineering and scientific fields, the meeting of October 27 will be devoted to "The Vitaphone." Much has appeared in the press relative to the recent application of this development on the New York stage. The complete story of the principles, development and operation of the vitaphone will be outlined to the members of the society and their friends in a popular talk by E. B. Craft, executive vice-president, Bell Telephone Laboratories, Inc. Following Mr. Craft, the president of the Vitaphone Corporation, Mr. Walter Rich, will speak on educational and other possibilities. There will follow actual demonstrations of the vitaphone with the reproduction of selections by famous stars. The meeting will be held in the Auditorium of the Engineering Societies Bldg., 33 West 39th St., New York, N. Y. at 8.15 p. m. on Wednesday, October 27, 1926. A cordial invitation is extended to members of the A. I. E. E. and others interested to be present as guests of the New York Electrical Society.

Philadelphia Convention of Civil Engineers

The official program for the Philadelphia Convention of the American Society of Civil Engineers, Oct. 4-9, 1926 gives details of the various treats in store for those who attend. Seldom has the Society been privileged to present a more imposing schedule.

Salient Features of Power and Mechanical Show

Fifth National Exposition of Power and Mechanical Engineering, Grand Central Palace, New York, N. Y.

Opening December 6 and continuing through December 11, 1926; will open at 12 noon each day and close at 10:30 p. m.

The Exposition performs the service of a great clearing house of latest information about important developments in power and mechanical engineering, as regards heat and power generating apparatus, hoisting and conveying equipment, power transmission equipment, machine tools, refrigerating machinery and heating and ventilating machinery.

The American Society of Mechanical Engineers will hold its Annual Meeting in the Engineering Societies Building, 29 West 39th Street, from December 6-9. The meeting of the American Society of Refrigerating Engineers will be held at the Hotel Astor from December 7-9.

In the conduct of the Exposition the management will be assisted by an Advisory Board of outstanding consulting engineers and officers from The American Society of Mechanical Engineers, the American Society of Refrigerating Engineers, the American Society of Heating and Ventilating Engineers, the National Electric Light Association and the National Association of Stationary Engineers.

Electrochemists to Discuss Electric Furnace Refractories

The American Electrochemical Society will hold its fiftieth national meeting, at Hotel Washington, Washington, D. C., October 7, 8 and 9. An elaborate program has been arranged by the local committee and preparations are being made for an unusually large attendance.

Electrical engineers will be particularly interested in the Symposium scheduled for Thursday morning, October 8th, at Hotel Washington. The symposium will be in charge of Dr. H. W. Gillett, of the Bureau of Standards, an engineer of world-wide reputation and an inventor of electric furnaces and other electrical devices. The symposium topic is "Materials for Extreme Conditions in the Electrochemical Industries."

The first paper of the symposium is by Dr. H. J. French, Senior Metallurgist, Bureau of Standards, who will discuss the principal characteristics and typical applications of metals used industrially to resist high temperatures or corrosion. Dr. J. G. Thompson will report the findings of the Fixed Nitrogen Research Laboratory at Washington and will offer recommendations as to the best materials for the nitrogen fixation industry.

The Carborundum Company, of Niagara Falls, have, during the last five years, carried out extensive tests on thermal insulation of electric furnaces and these tests will be reported on by Dr. M. L. Hartmann and Mr. O. B. Westmont. Mr. F. A. J. FitzGerald, the well-known electric furnace engineer of Niagara Falls, will present a communication on recrystallized carborundum, or silicon carbide.

The second half will be devoted to the refractory problem for the induction furnace which has been a more difficult one than the similar problem for the electric arc furnace. Mr. Max Unger, of the General Electric Co., Pittsfield works, inventor of the General Electric Induction Furnace, will describe at length his researches that led up to the solving of this very difficult refractory problem.

The Friday morning session will be devoted to papers on Electrodeposition. Mr. G. Prescott Fuller, engineer of the new Electrolytic Iron Plant at Niagara Falls, will describe the new process and product.

"Voltage Studies in Copper Refining Cells" is the title of a paper by Colin G. Fink and C. A. Philippi. A paper of special interest is that by J. D. Edwards and C. S. Taylor on "The Electrical Resistivity of Aluminum-Calcium Alloys." The last session of the meeting, Saturday morning, will be devoted to organic electrochemistry.

Among the social features of the program is a visit to the Government Laboratories. On Thursday evening there will be an informal dinner at which Prof. W. D. Bancroft, of Cornell University, will discourse on "The Ramifications of a Research Problem." The formal address of the convention will be delivered by Dr. Chas. Greeley Abbot, Director of the Smithsonian Observatory, at the National Academy of Sciences, on Friday evening, October 8th. The title of Dr. Abbot's address is "Solar Radiation."

At this same meeting, Honorary Membership in the American Electrochemical Society will be officially bestowed on Dr. Edward Weston, internationally known for his standard cell.

Fall Meeting of American Welding Society

One of the largest Welding Expositions will be held in connection with the Fall Meeting of the American Welding Society, Buffalo, N. Y., November 17, 18 and 19, 1926. This Exposition will show new developments in welding apparatus and supplies, and a unique feature will be an exhibit of a large variety of welded products. The Exhibit will open the day preceding the Annual Fall Meeting of the Society. Indications are that several thousand people will be in attendance at the various technical sessions, inspection trips, committee meetings and exhibits, in-

cluding representatives from all parts of the United States and Canada.

Technical sessions include authoritative papers and discussions on "The Design and Development of Welding Apparatus," "Organization of Welding on the Railroads;" "Welding of Locomotive Parts;" "Welding Science in the Engineering Curriculum of Universities;" and "Arc Welding in a Gaseous Atmosphere."

An inspection trip has been arranged to Niagara Falls, and members of the society and their guests will view the Falls from the American side with a short inspection trip through the Niagara Falls Power House. This will be followed by a buffet supper on the Canadian side and then a special illumination of the Falls will be shown, returning to Buffalo late in the evening.

Bituminous Coal Conference

The Conference on Bituminous Coal to be held at the Carnegie Institute of Technology in Pittsburgh has been definitely scheduled for November 15 to November 19, 1926, according to an announcement from the institution.

The purpose of the meeting, according to Dr. Thomas S. Baker, president of the Carnegie Institute of Technology, is to bring together the men of all countries who have done notable work in the study of more scientific and rational utilization of soft coal. Listed for discussion are such questions as the manufacture of substitutes for gasoline from coal; the complete gasification of coal; high temperature and low temperature carbonization; by-products; smokeless fuel; pulverized coal; hydro-electric power versus steam power, etc.

Among the members of the Advisory Board assisting in the development of the conference plans are Andrew W. Mellon, Secretary of the United States Treasury; John Hays Hammond, engineer and inventor; Otto H. Kahn, banker; Charles M. Schwab, steel manufacturer; Samuel Insull, public utility leader; E. M. Herr, president of the Westinghouse Electric and Manufacturing Company; and Dr. Frank B. Jewett, vice-president of the American Telephone and Telegraph Company, and director of research of the Bell Telephone Research Laboratories.

Standardization of Voltages Will Be a Winter Convention Topic

The standardization of voltages, and particularly of high voltages, has received much attention from the electrical industry for the last two years. Various organizations have been studying this question and, as a result, a group of central-station operating engineers, members of consulting and management organizations, electrical manufacturers and European engineers has arranged for the presentation of papers on this subject at the coming Winter Convention of the A. I. E. E., February 7-10, 1927. The committee on arrangements, of which B. G. Jamieson is chairman, has prepared the following announcement of its plans.

First, from a review made by the Apparatus Committee of the N. E. L. A., it appears that the standard voltages for transformers established in 1922 are not well adapted to meet the present conditions and less than half of all the power transformers above 200 kv-a. are being ordered in line with these standards.

Second, the increasing number of interconnections which are taking place has focused attention on the subject of uniformity of voltages, particularly in the high-pressure field.

The study by the Electrical Apparatus Committee of the N. E. L. A., which included the data received from operating companies in answer to a questionnaire, indicated that a revision of the 1922 transformer-voltage standards must take into account not only the present operating voltage of systems, but the voltage ratings of generators, oil circuit breakers and other electrical equipment connected on the same system, and finally, the utilization voltage.

In order to focus the attention of the industry on this subject and arrive at some concrete recommendations, it is proposed to devote one of the regular sessions of the Winter Convention to the discussion of this subject. The papers presented at this meeting will cover the points of view of different groups in the electrical industry as well as the different requirements of the field served in different localities. The subject is of such far-reaching importance that foreign engineers will be brought into the discussion and present their view as they see it in their countries; and the electrical manufacturers will present their view as to the effect of equipment on production if new standardization can be made along this line.

A tabulation was published in the N. E. L. A. Bulletin for September setting forth a proposed set of standard voltages for systems, generators, transformers, motors, and other electrical apparatus, all interdependent and fitting together in such a way that, with system voltages and apparatus voltages selected according to the proposed standards, a system will work under any reasonable condition of load and voltage drop. This was published as a foreword to the discussion of the Winter Convention.

It is hoped that all engineers interested in this problem will be prepared to enter into the discussion at the Winter Convention, and if they will advise Institute headquarters, advance copies of the papers will be sent to them prior to the meeting.

National Electrical Manufacturers Association

The creation of a National Electrical Manufacturers Association, consisting of 270 leading electrical interests, has been announced following the merging of the Electric Power Club, the Associated Manufacturers of Electrical Supplies and the Electrical Manufacturers Council. Gerard Swope, President of the General Electric Company and Fellow of the Institute, has been elected President of the new association, with James William Perry, Treasurer. Mr. Perry is also a Member of the Institute.

The general purpose of the new association is to advance the art and reliability of electrical equipment; specifically, to further the interests of makers of electric apparatus and supplies, engineering safety, transportation and other industrial problems; to promote the possible standardization of electrical apparatus by the collection and dissemination of information of value to members of the electrical profession and to the public; to appear for legislative movements, before governmental bureaus and to create a spirit of wide cooperation for the betterment of electrical developments.

Election of Officers of the A. I. E. E.

The actions specified in the Institute's Constitution and By-laws relative to the organization of a National Nominating Committee are being taken, and the meeting of the National Nominating Committee for the nomination of officers to be voted upon at the election in the Spring of 1927 will be held between November 15 and December 15. All suggestions for the consideration of the National Nominating Committee must be received by the Secretary of the Committee at Institute headquarters, New York, not later than November 15.

The sections of the Constitution and By-laws governing these matters are quoted below:

CONSTITUTION

28. There shall be constituted each year a National Nominating Committee consisting of one representative of each geographical district, elected by its Executive Committee, and other members chosen by and from the Board of Directors not exceeding in number the number of geographical districts; all to be selected when and as provided in the By-laws; The National Secretary of the Institute shall be the secretary of the National Nominating Committee, without voting power.

29. The executive committee of each geographical district shall act as a nominating committee of the candidate for election as Vice-President of that district, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The National Nominating Committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The National Nominating Committee shall name on or before December 15 of each year, one or more candidates for President, Treasurer and the proper number of Managers, and shall include in its ticket such candidates for Vice-Presidents as have been named by the nominating committees of the respective geographical districts, if received by the National Nominating Committee when and as provided in the By-laws; otherwise the National Nominating Committee shall nominate one or more candidates for Vice-President(s) from the district(s) concerned.

BY-LAWS

Sec. 21. During September of each year, the Secretary of the National Nominating Committee shall notify the Chairman of the Executive Committee of each Geographical District that by November 1st of that year the Executive Committee of each District must select a member of that District to serve as a member of the National Nominating Committee and shall, by November 1st, notify the Secretary of the National Nominating Committee of the name of the member selected.

During September of each year, the Secretary of the National Nominating Committee shall notify the Chairman of the Executive Committee of each Geographical District that by November 15th of that year a nomination for a Vice-President from that District, made by the District Executive Committee, must be in the hands of the Secretary of the National Nominating Committee.

Between October 1st and November 15th of each year, the Board of Directors shall choose five of its members to serve on the National Nominating Committee and shall notify the Secretary of that Committee of the names so selected, and shall also notify the five members selected.

The Secretary of the National Nominating Committee shall give the fifteen members so selected not less than ten days' notice of the first meeting of the committee, which shall be held not later than December 15th. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the National Nominating Committee must be received by the Secretary of the committee by November 15th. The nominations as made by the National Nominating Committee shall be published in the January issue of the A. I. E. E. Journal, or otherwise mailed to the Institute membership during the month of January.

F. L. Hutchinson,
National Secretary

George Westinghouse Memorial Committee Appointed

A committee chosen from among executives of the Westinghouse corporations has been named to represent the enterprises founded by George Westinghouse in the work of erecting a memorial to him in Schenley Park, Pittsburgh, Pa. to perpetuate esteem for his life and work.

The committee consists of A. L. Humphreys, president of the Westinghouse Airbrake Company, chairman; E. M. Herr, president of the Westinghouse Electric and Manufacturing Company; F. A. Merrick, vice president of the Westinghouse Electric and Manufacturing Company, and John F. Miller of the Westinghouse Airbrake Company, vice chairman.

AMERICAN ENGINEERING COUNCIL

MEETING OF ADMINISTRATIVE BOARD

The Administrative Board of the American Engineering Council will meet at Ithaca, N. Y., November 11 and 12. Reports will be received from numerous committees which have been active during the summer. Among the topics in the large agenda which is being prepared are safety and production, registration of engineers, government reorganization, and jurisdictional strikes in the building industry. Dean Dexter S. Kimball of Cornell University, the president of the Council, will preside.

NATIONAL SURVEY TOWARD INDUSTRIAL SAFETY

Charles W. Lytle, Director of Industrial Cooperation of the Engineering College at New York University, has been appointed to direct field investigations in New York as a part of a nationwide survey by the American Engineering Council, which seeks to check the growing number of industrial accidents in this country.

Two thousand industrial plants will be investigated by the engineers under the direction of a main committee headed by A. W. Berresford of Detroit, Past president of the Institute, with a view, according to the President of the Council, Dean Dexter S. Kimball of Cornell University, of getting to the bottom of the whole problem of accident prevention.

Industrial Accidents Discussed

The thirteenth annual meeting of the International Association of Industrial Accident Boards and Commissions will be held at Hartford, Conn., September 14-15, it was announced September 8 by the Bureau of Labor Statistics. The association is made up of State and city organizations' representatives.

Ethelbert Stewart, United States Commissioner of Labor, will attend as representative of the Department of Labor. He also is secretary-treasurer of the association, the sessions of which will be held in the hall of the House of Representatives, in the State Capitol at Hartford.

The meetings will be addressed by many of the leading authorities on industrial accident prevention. Special attention will be given to medical problems that may be made to assist industrial workers.

Would Standardize Motor Vehicles for Government

Announcement of an inquiry into the possibility of standardizing motor propelled vehicles for use by the Government was made in the annual report of the Federal Specifications Board. The work will be started by a preliminary technical committee.

The committee was instructed to study the question of motor-vehicle standardization from the standpoint of saving in replacement and repair as well as the utilitarian possibilities of a standard machine being used by every branch of the Government.

In addition to this committee, others were created to study standard specifications for such things as foundry equipments and supplies, machinery and commercial wire. The report also disclosed that 114 master specifications for Government supplies were promulgated during the last fiscal year.

PERSONAL MENTION

M. Merwin Eells has resigned from his position as research engineer for the Western Coil and Electrical Company of Racine, Wisconsin, to become chief engineer of the Buckwalter Radio Corporation of Chicago.

A. Barnett Green, formerly of Murrie & Co., Appraisal Engineers and the Electrical Division of the New York Municipal Railway Corporation, has opened an office in the Marbridge Building, 1328 Broadway, New York City for the editing of engineering matter, compiling of data and the writing of advertising copy.

Doctor Edward Weston, Past President and Charter Member of the Institute, will have Honorary Membership in American Electrochemical Society bestowed upon him at their October 8th meeting, Hotel Washington, Washington, D. C. Doctor Weston, in 1875, established in Newark, N. J., the first factory in America devoted exclusively to dynamo electric machines. He is also the inventor of the Weston Measuring Instruments and holds several patents on electric lighting and other electrical devices.

Burch Foraker, for many years with the New York Telephone Company, and ultimately serving it as General Manager, has recently removed to Detroit to become President of the

Michigan Bell Telephone Company, as successor to the late Judge Franz C. Kuhn.

GEORGE M. BATES, who has been Manager of the Central Station Division of the Westinghouse Electric & Mfg. Co., Boston, Mass., has been chosen as District Manager of the new Boston office opened by the American Brown Boveri Electric Corporation. Mr. Bates had been with the Westinghouse Company since 1898.

YASUDIRO SAKAI, Consulting Engineer and Member of the Institute, announces the opening of a new office in Room 465, Marunouchi Bldg., Tokio, Japan. Mr. Sakai is a patent expert and is specially equipped to handle applications for Japanese "Letters Patent" and trade mark registrations.

CARL GEORGE SCHLUEDERBERG, previously assistant to the manager, Supply & Merchandising Depts. of the Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa., has been appointed General Manager of the George Cutter Company, South Bend, Ind. Mr. Schluederberg is a member of the N. E. L. A., the American Chemical Society, the American Electrochemical Society and the American Institute of Electrical Engineers.

EDWARD E. HILL, who has for some time been assistant superintendent in the Meter Dept. of the New York Edison has been advanced to Manager of the Meter Dept. Mr. Hill has been a member of the Institute since 1916 and is at present vice-chairman of the National Meter Committee, Engineering Division of the National Light Association as well as chairman of their Engineering Division of the Metropolitan New York Section.

Obituary

Charles Hampton Bedell, born Dec. 18, 1861, Lynn Co., Ia., died at his home, New London, Conn., Sept. 2, 1926.

In 1888 he became head of the Research Laboratory of the Electro Dynamic Co. of Philadelphia, and remained with them in that capacity until 1909. He then joined the Electric Boat Co., Groton, Conn., with whom he was up to the time of his death. In 1887 he received the degrees of B. S. and A. M. from Haverford College also taking one years electrical course at John Hopkins University.

Mr. Bedell joined the Institute in 1903.

James Warren McCrosky, 57 years old, died in Pasadena, California, July 20, 1926. From 1896 to 1902 he was engaged in engineering work in Argentina, where he designed, constructed and operated the first commercial electric railways and the first hydroelectric plant in that country. From 1902 to 1914, he was in London with J. G. White & Company, Ltd., doing engineering work and negotiating contracts. During the World War he served as one of the six members of the Contraband Committee of the War Trade Board. After the War he spent five years with the Bankers Trust Company, as manager of the Foreign Trade Department, retiring from business in 1924. He was a Fellow of the American Institute of Electrical Engineers, a member of the Engineers Club of New York and the Bankers Club of America, and of the Pan-American Society.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (AUGUST 1-31, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

AEROSTATICS.

By Edward P. Warner. N. Y., Ronald Press Co., 1926. (Ronald aeronautic library). 112 pp., diagrs., 9 x 6 in., cloth. $3.25.

A textbook based upon the first part of a course in the theory of airship design given at the Massachusetts Institute of Technology.

AIRCRAFT POWER PLANTS.

By Edward T. Jones and others. N. Y., Ronald Press Co., 1926. (Ronald aeronautic library). 208 pp., illus., diagrs., 9 x 6 in., cloth. $4.25.

This book is not intended so much for those engaged in building or operating engines, as for designers of aircraft, who need to know something of the characteristics of the power plants in order to adapt them to the structures they design, and for pilots who need knowledge of the engine to operate their craft successfully. The book discusses the various types of heat engines from a thermodynamic point of view, pointing out the advantages and disadvantages of each and the factors that affect performance. Propellers are treated in the same fashion. The concluding section treats of water ballast recovery.

CALCULUS.

By Herman W. March and Henry C. Wolff. 2nd edition. N. Y., McGraw-Hill Book Co., 1926. 398 pp., 7 x 5 in., cloth. $2.50.

An elementary textbook for beginners who are students of science or technology. The authors have endeavored, while developing the fundamental processes of the calculus, to place the emphasis upon the mode of thought and to show how this mode of thought fits naturally into the expression and derivation of scientific laws and of natural concepts. This method of presentation will lead the student, they hope, to continue to apply these fundamental modes of thinking throughout his career, even though he may forget the details of the subject.

CONQUESTS OF ENGINEERING.

By Cyril Hall. Lond., Blackie & Son, Ltd., [1926]. 288 pp., illus., 8 x 5 in., cloth. 3s 6d.

Bridges, tunnels, canals, lighthouses and docks are the works discussed in this popular account of civil engineering. The author writes in interesting fashion of the way in which these works are designed and built and tells the story of some famous examples. Intended for the general reader.

Diesel Engines: Marine—Locomotive—Stationary.

By David Louis Jones. N. Y., Norman W. Henley Publ. Co., 1926. 565 + 39 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

A manual for operators of Diesel engines, prepared by the instructor in the Diesel engine department of the U. S. Navy Submarine School. Keeping in mind the class for which he writes, the author devotes but little time to theoretical principles, thermodynamic considerations, etc., but gives most of his attention to the actual construction and the operation of the various parts of commercial engines, to advice on operation and to descriptions of typical engines. The book should be helpful to all in charge of Diesel power plants.

Elektrische Schaltvorgange.

By Reinhold Rüdenberg. 2nd edition. Berlin, Julius Springer, 1926. 510 pp., illus., diagrs., 10 x 7 in., cloth. 24 r. m.

An exhaustive discussion of the phenomena that accompany switching operations and of the disturbances that they cause in heavy-current lines. Dr. Rüdenberg, who is chief electrician of the Siemens-Schuckertwerke, takes the various kinds of circuits, one by one, and the switching operations to which each may be subjected, and deals fully with the mathematical theory of the phenomena that occur.

This edition is much the same as the first, but small errors have been corrected, the bibliography completed through 1925 and an index added.

Die Fernsprechanlagen mit Wahler-Betrieb.

By Fritz Lubberger. 3rd edition. Mün. u. Ber., R. Oldenbourg, 1926. 277 pp., plates, 10 x 7 in., paper. 11,-mk.

A systematic discussion of the problems involved in the construction of an automatic telephone system, the possible methods of solving them and the advantages and disadvantages of these various possibilities. The discussion is limited to technical phases of the subject, economic questions being left for a separate treatment. The six leading commercial systems are described in detail.

Les Filtres Electriques.

By Piere David. Paris, Gauthier-Villars et cie., 1926. 129 pp., diagrs., tables, 10 x 7 in., paper. 25 fr.

The first part of this treatise endeavors to recapitulate, in a new way, the essential points of the theory of electric filters. His work is intended especially to make available to French electricians the results obtained by American investigators, particularly those connected with the Bell system. The second part treats of practical matters. In it the theoretical results are grouped so as to facilitate practical application of filters to various purposes.

Handbook of Non-Ferrous Metallurgy.

By Donald M. Liddell, Editor-in-Chief. N. Y., McGraw-Hill Book Co., 1926. 2 vols., illus., diagrs., tables, 9 x 6 in., cloth. $12.00.

This handbook will be valued by engineers and metallurgists who wish a concise account of modern metallurgical methods, as well as by students. Each topic has been handled by an author acquainted with it through experience.

The first volume treats of processes and materials that are common to all metallurgical operations. It contains chapters on crushing and grinding, sampling, screening, classification, concentration, dewatering, fuels, refractories, briquetting, power plants, plant materials, plant layout and electric furnaces. In volume two a chapter is devoted to the metallurgy of each metal.

Hydrology and Ground Water.

By J. M. Lacey. Lond., Crosby Lockwood & Son, 1926. 159 pp., diagrs., 9 x 6 in., cloth. 12s 6d.

The want of a comprehensive work on hydrology, ground water and surface flow, has induced the author to compile this work. It is intended to aid engineers engaged in schemes for water works, irrigation or drainage.

International Critical Tables of Numerical Data, Physics, Chemistry and Technology.

Prepared under the auspices of the International Research Council and the National Academy of Sciences by the National Research Council of the United States of America. 1st edit. N. Y., McGraw-Hill Bk. Co., 1926. 415 pp., diagrs., 11 x 9 in., cloth. $60.

This book, the result of the cooperative work of many specialists, gives the values for physical and chemical constants which they have selected as the "best" values, from the great mass of determinations recorded in scientific and technical literature before the year 1924. It selects, in each case, the value that appears most worthy of credence and makes it available readily.

The need for such a reference book has long been obvious. The seeker after data, who has usually been confronted by several values, with no means of criticizing their relative accuracy, will be much relieved to have a selected figure which has the stamp of authority. The book is a necessity to every laboratory and scientific library.

In a sense, the work supplements the "International Annual Tables of Constants." It removes the necessity of examining all the volumes of the latter in most cases, by giving immediately the prepared value.

Kran- und Transportanlagen fur Hutten-, Hafen-, Werft-, und Werkstattbetriebe.

By C. Michenfelder. 2nd edition. Berlin, Julius Springer, 1926. 683 pp., illus., diagrs., 11 x 8 in., boards, 67, 50 mk.

An extensive descriptive treatise on modern hoisting and conveying machinery, particularly as used in smelters, rolling-mills, shipyards and harbors. The work is intended to assist in the selection of equipment rather than to aid in design and therefore the text follows the course of operations in these various industries, explaining the problem of transportation at each operation and the ways by which it can be met. The book is a useful detailed description of current German practise, illustrated with many photographs of machines and installations.

Mathematics for Engineers.

By Raymond W. Dull. N. Y., McGraw-Hill Book Co., 1926. 780 pp., 8 x 5 in., cloth. $5.00.

The two sources to which the engineer turns for mathematical aid are the engineer's handbook and the mathematical textbook. The first of these, Mr. Dull says, is too concise and incomplete to be satisfactory; the second is not well adapted to use for quick reference.

The present book, prepared by a practising engineer, appears to be primarily intended as a convenient work of reference and as a means for reviewing various topics. The entire range of mathematics ordinarily used in engineering is traversed, the examples are worked out with greater fulness than usual and the text is arranged to facilitate ready understanding of each question. Graphical solutions are included and a considerable treatment of absolute and relative errors is given.

North Manchuria and the Chinese Eastern Railway.

By I. A. Mihailoff, editor. Harbin, China, Chinese Eastern Railway, 1924. 454 pp., illus., maps, 12 x 9 in., fabrikoid. Price not quoted.

A systematic account of industrial conditions in North Manchuria, prepared by the Economic Bureau of the Chinese Eastern Railway. Data are given on agriculture and forests, on the trade in grain, cattle, lumber and coal, on milling and manufacturing, on banking, currency, etc. Ways of communication, especially the Chinese Eastern Railway, are described. The book contains many photographs.

On the Metallurgy of Iron and Steel.

By F. T. Sisco, Bengt Kjerrman and Birger Egeberg. Amer. Soc. Steel Treating, Cleveland, Ohio. 1926. 193 pp., illus; $1 paper cover, $2 cloth binding.

This book is a reprint of three papers presented before the American Society for Steel Treating recently, which attracted so much attention that there was a demand for their separate publication. Mr. Sisco's discussion of the metallurgy of iron and steel constitutes nearly seven-eighths of the book; Dr. Kjerrman contributes 10 pages on Swedish steel practise and Dr. Egeberg adds 5 pages on electric steel melting. The reprint will be extremely useful to any one who wishes a brief, clear, and accurate statement of the general features of iron and steel metallurgy, especially to both technical and non-technical employees of steel companies who wish to obtain a better understanding of the business they are engaged in.

Phototopography; a Manual of Photographic Surveying Methods.

By Arthur Lovat Higgins. Cambridge, University Press, 1926. 130 pp., illus., diagrs., plates, 8 x 5 in., cloth. $2.40. (Gift of Macmillan Co., N. Y.)

The author has attempted to outline the essential principles of the operations of some of the best-known exponents of the photographic method and thus to produce a practical manual for surveyors and students.

PORTS AND TERMINAL FACILITIES.

By Roy S. MacElwee. 2nd ed., enl. N. Y., McGraw-Hill Book Co., 1926. 446 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

The new edition of this work is actually, the author says, a new book, containing less than fifteen per cent of the original work. That portion of the older edition which dealt with the upbuilding of traffic through competitive ocean gateways now appears as a separate work entitled "Port Development," while the volume before us discusses the construction and equipment of ports.

The book first discusses general matters, the characteristics of well coordinated seaports and wharf design. Equipment and arrangements for general cargo wharves and warehouses are described in detail, after which attention is given to passenger terminals and facilities for handling ore, coal, liquids and grain in bulk. The concluding chapter discusses industrial harbor development.

LE PROBLEME ACTUEL DU CONDENSEUR A SURFACE.

By A. Delas. Paris, Revue Industrielle, 1926. 22 pp., illus., 8 x 5 in., paper. 5 fr.

Describes the results of recent researches which have increased the efficiency of surface condensers by rearrangement of the condenser tubes. These rearrangements have made it possible, at the Gennevilliers power plant, to suppress one-fourth of the tubes in certain of its condensers.

PROPRIETES PHYSIQUES DES VAPEURS DE PETROLE ET LES LOIS DE LEUR ECOULEMENT.

By Jean Rey. Paris, Dunod, 1925. 251 pp., diagrs., plates, tables, 9 x 6 in., paper. 8,50 Fr.

The author has found it necessary, in connection with his professional work, to undertake an extensive investigation of the physical properties of kerosene. In this memoir he presents the results of his researches.

In part one the numerical values he has obtained are used to determine approximately the law of variation, with the temperature or pressure, of the physical properties of kerosene: vapor tension, heat of vaporization, liquid density, specific heat, etc. The second part describes the apparatus used in the researches, and the application of the burners invented by the author to boilers and lighthouses.

RADIOACTIVITY.

By George Hevesy and Fritz Paneth; trans. by Robert W. Lawson. Lond. & N. Y., Oxford Univ. Press, 1926. 252 pp., illus., diagrs., tables, 9 x 6 in., cloth. 15 s.

Hevesy and Paneth's Radioactivity first appeared in the German language in 1923. Translations into Russian and Hungarian were published in 1924 and 1925, and now comes the present English version. This last is not a literal translation of the original work, but is essentially a new edition, for the authors have incorporated in it the results of scientific advances since the German edition appeared and have extended the bibliographic references up to 1925.

The book differs from the majority of those on the subject by being intended specifically for use as a textbook, a work which will give those having no preliminary knowledge of radioactivity an insight into the science at first hand. The subject matter is arranged from the didactic point of view, somewhat as is done in textbooks of physics and chemistry, the historical development of the subject being separated and outlined late in the book.

RATIO CHART IN BUSINESS.

By Percy A. Bivins. N. Y., Codex Book Co., 1926. 177 pp., charts, 8 x 6 in., cloth. $3.00.

A clear, detailed description of the methods of making ratio or logarithmic charts and thorough explanation of many of its applications in industry and business. The author treats the subject in simple language, readily understood by those unfamiliar with the subject, and the book should do much to popularize this valuable method.

LES RESERVES D'ENERGIE.

By M. Rigaud. Paris, Gauthier-Villars & cie., [1926]. 295 pp., 8 x 5 in., paper. 30 fr.

Discusses, from a broad viewpoint, the possible sources of energy and present utilization of them. Beginning with the kinetic energy of the earth and the utilization of tidal power, the author then considers the internal energy of the earth. Radient energy from the sun is discussed, with its indirect utilization by winds and direct utilization by falling water. Turning then to mineral fuels, the winning and use of coal and oil are treated.

SCIENCE OF FLIGHT AND ITS PRACTICAL APPLICATION, Vol. 1; Airships and Kite Balloons.

By P. H. Sumner. Lond., Crosby Lockwood & Son, 1926. 168 pp., illus., diagrs., tables, 9 x 6 in., cloth. 16s.

After an introductory chapter on the British air policy, Captain Sumner takes up successively the principles of aerostatics, the general construction of the dirigible, the airship in flight, the types of airships and their performances, and kite balloons. The book, which is the first of two volumes on the general subject of flight, is devoted to buoyant airships. It is based on the author's long experience in airship construction in the Air Ministry.

TABLES ANNUELLES DE CONSTANTES ET DONNEES NUMERIQUES DE CHIMIE, DE PHYSIQUE ET DE TECHNOLOGIE. Vol. 5, pt. 2, 1917-1922.

Publiées sous le patronage de l'Union de Chimie pure et appliqué. Paris, Gauthier-Villars et cie, Cambridge, Eng., Cambridge University Press; Chicago, Univ. of Chicago Press. 1926. 1130 pp., 11 x 9 in., cloth. $25.00 (pts. 1 and 2).

A new volume of this indispensable collection of chemical and physical data, containing tables showing those recorded during the years 1917-1921.

With the publication of this volume, the interruption caused by the war has been made up. A volume covering the years 1924 and 1925 will probably appear early next year, and it is the hope of the Committee soon to make the publication again an annual.

THERMODYNAMICS AND CHEMISTRY.

By F. H. Macdougall. 2nd edition. N. Y., John Wiley & Sons, 1926. 414 pp., tables, 9 x 6 in., cloth. $5.50.

A textbook for advanced students of chemistry, which aims to give an accurate, logical and sufficiently rigorous exposition of thermodynamics, with numerous examples of the application of the principles to their work. The new edition is enlarged and partly rewritten.

THEORY AND PRACTISE OF RADIO FREQUENCY MEASUREMENTS.

By E. B. Moullin. Lond., Charles Griffin & Co.; Phila., J. B. Lippincott Co., 1926. 278 pp., diagrs., tables, 9 x 6 in., cloth. 25 s.

The author has aimed to write a work that will serve as a handbook for use and reference on the laboratory table while measurements are in progress. It will also be usable as a textbook for advanced students.

The subjects covered are the measurement of potential difference, current, frequency, resistance, capacity, inductance, antenna characteristics, and the intensity of radiated fields. The book is based on the experience of the author and the isolated papers scattered through the scientific journals. It is, the author believes, the first book devoted entirely to the subject.

TRANSPORT AVIATION.

By Archibald Black. N. Y., Simmons-Boardman Pub. Co., 1926. 245 pp., illus., tables, 9 x 6 in., cloth. $3.00.

A discussion of the various problems connected with commercial aviation. The author describes present developments here and abroad and studies the possibilities of the airplane as a means of transportation. He discusses the influence of design upon the cost of operation, general requirements of airplanes for commercial use, the design of passenger and freight airplanes, airways, landing fields and the organization of air lines. Cost data are scattered through the book.

UBER DIE WAHL EINES GASWERKSOFENSYSTEMS.

By L. Litinsky. Halle (Saale), William Knapp, 1926. 29 pp., illus., 10 x 7 in., paper. 1,50 r. m.

In selecting the generators for a gas works the problem is to choose the type that will produce gas at the lowest cost per cubic foot, but many factors enter into the decision as to what constitutes the most economical equipment. The present pamphlet analyzes the various alternatives before the designer and points out the relative merits of each.

L'UNION D'ELECTRICITE.

By H. Bres. Paris, Revue Industrielle, 1926. 63 pp., illus., 8 x 5 in., paper, 10 fr.

A pamphlet describing recent additions to the Gennevilliers power station of the Union d'Electricité and installations of new machinery in its Vitry plant. The additions are 50,000-kw. turboalternators, pulverized-coal boiler plants and numerous other improvements on a large scale.

Past Section and Branch Meetings

SECTION MEETINGS

Atlanta

Annual Dinner. The following officers were elected: Chairman, C. E. Bennett; Vice-Chairman, E. H. Bailey; Secretary-Treasurer, W. F. Oliver. July 30. Attendance 55.

Kansas City

Electric Domestic Refrigeration, by B. J. George, Kansas City Power & Light Co., and

Flickering of Lights by a Sixty-Cycle Generator, by S. M. DeCamp, General Electric Co. June 7. Attendance 27.

Mexico

Talk by Gustavo Trevino, Mexican Telephone and Telegraph Co., upon the work his company is doing in Mexico. July 1. Attendance 25.

Oklahoma

Rural Electrification, by Edwin Kurtz, Oklahoma A. & M. College;

What the Employer Expects of a Young Engineer, by Frank Meyer, Oklahoma Gas and Electric Co., and

First Aid to the Injured, by N. I. Sommers. The following officers were elected: Chairman, E. R. Page; Vice-Chairman, Edwin Kurtz; Secretary-Treasurer, C. C. Stewart. May 26. Attendance 90.

Philadelphia

Electrical Features of the New Richmond Generating Station, by R. A. Hentz, Philadelphia Electric Co. Illustrated with slides. Inspection trip to the Generating Station. May 10. Attendance 172.

Dinner Meeting. The following officers were elected: Chairman, L. J. Costa; Secretary, R. H. Silbert; Treasurer, E. C. Drew. A short talk was given by Mr. William McClellan on the problems confronting the electrical industry today. June 14. Attendance 85.

Portland

Get-Together Meeting. Joint with National Electric Light Association, American Society of Mechanical Engineers and American Society of Mining and Metallurgical Engineers. June 19. Attendance 212.

St. Louis

Introduction of Machine Switching Telephony in St. Louis, by J. H. Landwehr, Southwestern Bell Telephone Co. The following officers were elected: Chairman, Walter Millan; Secretary, L. N. Van Hook. May 19. Attendance 128.

Utah

Business Meeting. The following officers were elected: Chairman, B. C. V. Wheatlake; Secretary-Treasurer, D. L. Brundige. August 6. Attendance 25.

BRANCH MEETINGS

University of California

Business Meeting. August 25. Attendance 31.

Ohio Northern University

Business Meeting. September 9. Attendance 36.

Rutgers University

Business and Social Meeting. The following officers were elected: Chairman, E. C. Siddons; Vice-Chairman, Frank Chalten; Secretary-Treasurer, W. H. Bohlke. May 10. Attendance 31.

University of Southern California

Business Meeting. May 13. Attendance 25.

Business Meeting. The following officers were elected: Chairman, Karl Raife; Vice-Chairman, Lester Weisser; Secretary, Elwood Smith; Treasurer, Willard Bausman. May 20.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL ENGINEER, with three or four years' experience in design of electrical layouts for generating and substations for positions in engineering department of public utility. Apply by letter. Location, South. X-644-C-S.

DIRECT CURRENT MACHINE DESIGNER, experienced, for medium industrial sizes. Apply by letter stating technical training, experience, age and salary expected. Opportunity. Location, Pennsylvania. X-658-C-S.

BOILER ROOM ENGINEER, for new public utility station in South, operating high-pressure boilers. Must have oil-burning experience and be capable supervising operation and maintenance. Apply by letter giving full details of experience, and salary expected. Headquarters, New York City. X-695.

ILLUMINATING ENGINEER, capable supervising design and production of floodlighting units, searchlights and other illuminating equipment. Also with ability to make layouts and installation recommendations on special floodlighting work. Apply by letter stating age,

education, experience, salary desired. Headquarters, Philadelphia. X-738-C.

ELECTRICAL DESIGN ENGINEER, on large direct current machines having at least five years' design experience; experience in steel mill applications of direct current motors is desirable. Apply by letter, giving full particulars concerning age, technical education, design experience, references, salary expected, and date when available. Apply by letter. Location, Pennsylvania. X-819-C.

ELECTRICAL AND MECHANICAL ENGINEER, preferably graduate, under 40, experienced in design and manufacture of switches, fuses, panel boards, receptacles, and similar electrical accessories, as general assistant to chief engineer of concern producing such devices. Should be willing and able to work at the board and handle small as well as big jobs. Opportunities. Apply by letter. Location, East. X-628.

MEN AVAILABLE

ELECTRICAL ENGINEER, 31, married, desires position with a manufacturing or engineering concern. Several years' laboratory experience in development work. Recently production manager for non-electrical firm. Now available. New Jersey, Pennsylvania, or Middlewest preferred. C-1798.

RECENT GRADUATE IN ELECTRICAL ENGINEERING desires position with large concern. Had two years' experience installing central office telephone equipment. Prefers position along experimental and research lines. C-1813-8-C-3.

PLANT ENGINEER, 33, married, thorough training in taking responsibility and handling of men. Thirteen years' experience on mechanical and electrical maintenance, construction and installation work in steel mills, blast furnaces, zinc spelters, acid plant, textile plants and small parts manufacture. New York State Professional Engineer's License. Available at once. Location, Eastern United States (small town preferred). B-5026.

GRADUATE ELECTRICAL ENGINEER wishes connection with large power company or consulting firm. Two years' general test experience with large manufacturing company, one year station test with large metropolitan power and light company, two years general engineering with large metropolitan power company specializing in problems involving relay work and general system protection. B-7797.

ENGINEER CHARGE OF PLANT, for manufacturing concern with future prospects of branch superintendency sought by graduate E. E., 32, married. Nine years' experience including hydro plant preliminaries, design with field installations, construction and maintenance of lines transformers, substation A-C. and D-C., trolley, automatic control, pumps, fans, compressors and hoists, night school teaching. Now employed, but available on short notice. C-1828.

DISTRIBUTION ENGINEER, technical graduate, 33, married, several years' electrical and mechanical test experience in power stations, four years' distribution experience with large public utility in East. Desires position in distribution engineering, or sales engineering in distribution field. Location, East. Available one month. Salary $260. B-1410.

ELECTRICAL ENGINEER, 36, professionally licensed in the States of New York, New Jersey and Pennsylvania, with sixteen years' experience covering design, construction, supervising, estimating, contracting, sales, consultant and executive, desires to locate where opportunity is available. B-6985.

ELECTRICAL ENGINEER, 26, married, technical graduate, four years' experience test supervision with a-c. public utility, one year's experience teaching, executive, statistician, organizer. Desires position with progressive organization offering reasonable advancement for conscientious, energetic worker. C-1346.

UTILITY ELECTRICAL ENGINEER, ten years' experience in design of power stations and substations. Past two years in responsible charge of important projects for one of the countries largest systems, covering every phase of the work. Desires position with utility or holding company in or near New York City. Minimum salary $350 a month. B-7809.

ELECTRICAL ENGINEER, with twenty years' practical experience in industry and utility, desires position of responsibility in a growing organization with modern business policies. Research and developmental department on small electro-mechanical apparatus desired, meters and instruments a specialty. At present employed in charge of laboratory. C-1867.

JUNIOR SALES ENGINEER, technical school graduate, good appearance and personality. Experience; two years electrical maintenance, one year signal system work, one year industrial motor inspection for public utilities, one year electrical estimating and drafting for electrical contractors. Age 30, single. Available now. Salary open. Location, East. B-7920

COLLEGE GRADUATE, '25 in E. E., desires position where he can acquire experience either in appraisal or construction work. Available two weeks. Location, New York. C-512.

ELECTRICAL ENGINEER desires executive position with progressive company. Has had twenty years' experience in the manufacture, operation, repair, maintenance of electrical machinery and equipment. such as power plants, steel mill drives, street railway, mining equipment. For the past eleven years has had full charge of repairs, machine work, maintenance all electrical equipment for large steel plant. Location immaterial if salary is right. C-1879.

ELECTRICAL ENGINEER, 35, single, ten years' experience in the design and construction of generating stations, substations. Transmission lines, underground systems with large public utility concerns, and five years with large electrical manufacturer in heavy plant sales and contract department, estimating, tendering and technical correspondence. Desires position as sales engineer United States or abroad. Available two weeks' notice. C-1827.

ENGINEER, experienced in the design, manufacture and application of switching equipment, desires permanent position with operating company or sales organization. Age 31, married. C-1886.

ELECTRICAL ENGINEER, 27, single, technical graduate, four years' experience installation, testing, research, and manufacturing supervision. Desires position, preferably in New York, with advancement opportunity. B-7270.

CANADIAN, electrical engineering education, expert photographer, experience in electrical contracting, theatrical lighting and marine engineering, some knowledge of photo-electricity, desires position. Age 23, unmarried. Available immediately. Location immaterial. C-1906.

RECEIVER, recently discharged wishes connection with public utility. Eighteen years' experience in management, operation and control of hydroelectric properties and general public utility business. Position of business management preferred rather than technical engineering B-6686.

TECHNICAL GRADUATE IN E. E., 29 years of age with three years' experience on central station electrical tests, distribution system estimates, pole line construction, two years on telephone apparatus inspection and circuit tests, two years on electric railways, development, tests and design of car equipment. Knows Spanish. Locate anywhere. C-1889.

ELECTRICAL ENGINEER, three years sales, electrical equipment, seven years construction, power house and substation steam and electric, four years valuation and cost accounting. Married. Location preferred, New York. C-68.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street, New York.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Lincoln Bouillou, 731 21st Avenue W., Seattle, Wash.
2.—W. A. R. Brown, Radio Corp. of America, 33 W. 42nd St. New York, N. Y.
3.—A. F. Buckley, 211 Sherman Ave., New York, N. Y.
4.—John C. Fretz, N. Y. & Queens Elec. Lt & Pr. Co., Long Island City, N. Y.
5.—William F. Gilman, Belgrade Lakes, Maine.
6.—S. G. Guth, 419 Hampton Ave., Wilkinsburg, Pa.
7.—Edward C. Hanson, Box 59, Pinelawn, N. Y.
8.—A. Hirth, 519 Lincoln Place, Brooklyn, N. Y.
9.—M. E. Jonson, 133 Ardsley Road, Schenectady, N. Y.
10.—Eric Kjellgren, 145 13th Street, Milwaukee, Wisc.
11.—Otto W. Lawrence, Avenue E., Bound Brook, N. J.
12.—D. F. McConnell, 402 N. Highland Ave., Pittsburgh, Pa.
13.—Jack Nile, 378 Bayden Ave., Hilton, N. J.
14.—J. P. Ortiz. N. Y. Edison Co., 23rd St & 4th Ave., New York, N. Y.
15.—I. T. Roberts, 2355 Prairie Ave., Evanston, Ill.
16.—Orville B. Weeks, 305 Martense St., Brooklyn, N. Y.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED SEPTEMBER 24, 1926

*BASS, OSWALD BURTON, 2nd Electrician, "Empress of Australia," Canadian Pacific Steamships, Ltd., Vancouver; res., Victoria, B. C., Can.

BERTHOLD, WOLF, Draftsman, New York Rapid Transit Corp., 85 Clinton St., Brooklyn, N. Y.

BEYRODT, KURT, Electrician, Bond Service Repair Co., 42 Bond St., New York, N. Y.

BROWN, JESTON FOSTER, Elec. Engg. Student, Tri-State College, Angola, Ind.

BRUMMAL, JACK S., Switchman, Kansas City Telephone Co., Kansas City, Mo.

*BRICKER, GEORGE WALTER, Jr., Public Utility Accountant, H. C. Hopson, Inc., 61 Broadway, New York; res., Brooklyn, N. Y.

BURKHARDT, GEORGE EDWARD, Laboratory Engineer, General Railway Signal Co., West Ave., Rochester, N. Y.

CHAPMAN, HENRY NORMANTON, Jr., Asst. Foreman, Engg. Dept., Woodward & Tierman Printing Co., 1519 Tower Grove Ave., St. Louis, Mo.

COOK, H. C., Electrical Superintendent, Day & Zimmermann, Inc., Saxton, Pa.

COOKE, LEIGHTON B., Electrical Engineer, Bell Telephone Laboratories, 463 West St., New York, N. Y.

COTTIER, JOHN PERCIVAL, Borough Electrical Engineer, Ohakune Borough Council, Mire St., Ohakune, N. Z.

COVINGTON, PRESTON M., Supt., Electric Light & Water Department, Red Springs, N. C.

DeCONLY, JULIAN COGGSALL, Consulting Engineer, 315 Bank of Italy Bldg., Los Angeles, Calif.

DEJONG, FRANZ, Supt. of Testing Division, Riegos y Fuerza del Ebro, S. A., Plaza Cataluna No. 2, Barcelona, Spain.

DENNEY, L. JOHN, Maintenance Engineer, Engg. Dept., Bell Telephone Co. of Penn., 416 7th Ave., Pittsburgh, Pa.

DOBERCK, WILLIAM A., Chief, Electrical Construction Dept., Andersen Meyer & Co., Ltd., Shanghai, China.

DOYLE, JOHN THOMAS, Engineer in charge, Westport Stockton Coal Co., Ngakawau, Westport, N. Z.

DUNLAP, BERT, Division Maintenance, Ozark Pipe Line, Ponca City, Okla.

ELWORD, AURIOL, Smoke Tested, Consolidated Mining & Smelting Co. of Canada, Ltd., Trail, B. C., Can.

EYTON, JOHN, Service Dept., Canadian Westinghouse Co., Ltd., 512 William St., Montreal, Que., Can.

GARDNER, WILLIAM, Plant Dept., New York Telephone Co., 227 E. 30th St., New York, N. Y.

GERST, PAUL ERNEST, Electrical Draftsman, Engg. Dept., Commonwealth Edison Co.' 72 W. Adams St., Chicago, Ill.

HARRIS, CLAIR ASHLEY, General Foreman, Bureau of Reclamation, Emmett, Idaho.

HEARD, WILLIAM LAUREN, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., East Orange, N. J.

HILL, LEON ALBERT, Fieldman, Pacific Tel. & Tel. Co., 165 S. Howard St., Spokane, Wash.

JORDAN, ESSEX F., City Electrical Inspector, City of Roanoke, 401 Anchor Bldg., Roanoke, Va.

KALE, PURUSHOTTAM B., Managing Director, The Central Provinces Engineering Co., Ltd., Nagpur & Jubbulpore, Mount Road, Nagpur, India.

KEGL, ZOLTAN JOSEF, Asst. to Manager, York Insulated Wire Works of General Electric Co., York, Pa.

KENT, HARRY GORDON, Power Sales Engineer, Binghamton Light, Heat & Power Co., Binghamton, N. Y.

KIRSCH, MYER JACK, Experimental Engineer, Petroleum Heat & Power Co., Stamford, Conn.

KOTHAWALA, KERSHASP R., Electrical Engineer, Kishangarh State, Kishangarh, Rajputana, India.

LEMMON, JAMES ABEL, Sales Engineer, Diehl Mfg. Co., Elizabeth, N. J.

LENEHAN, CHARLES V., Deputy Asst. Supt., The New York Edison Co., 44 W. 27th St., New York, N. Y.

LOPEZ, CHARLES EDWARD, Chief, Electrical Dept., Cia. Huanchaca de Bolivia, Pulacayo, Bolivia, S. Amer.

LESSMANN, GERHARD, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

MARRISON, WARREN ALVIN, Laboratory Engineer, Bell Telephone Laboratories, 463 West St., New York, N. Y.

McKENZIE, MALCOLM THOMAS, Meter Foreman, Savannah Electric & Power Co., Cor. Bay & Whitaker Sts., Savannah, Ga.

MESSENGER, THEODORE IVES, Application Engineer, Monitor Controller Co., 7016 Euclid Ave., Cleveland, Ohio.

MONTGOMERY, DOUGLAS, Electrical Engineer, Cia. Mexicana Luz y Fuerza Motriz, Mexico, D. F., Mex.; *for mail*, Pasadena, Calif.

MOORE, HARRY ALBERT, Park Utah Consolidated Mines Co., Park City, Utah

MORI, HIDE, Engineer, Dept. of Communication, Bureau of Electricity, Tokio, Japan.

MOULTON, FRED EARL, Electrician & Lineman, Clyde River Power Co., Main St., Richford, Vt.

NORDHAUS, Charles H., Engineer, Grigsby-Grunow-Hinds Co., 4450 Armitage Ave., Chicago, Ill.

ODERMATT, ARNOLD, Engg. Dept., American Brown Boveri Electric Corp., Camden, N. J.

PADDOCK, WILLIAM GEORGE, Electrical Engineer, Lucknow Municipal Water Works, Aish Bagh, Lucknow, U. P., India.

PARKER, WILLIAM A. H., Sales Engineer, West Gloucestershire Power Co., Ltd., 21 Eastgate St., Gloucester, England.

*SANDERS, WILLIAM FERRELL, Electrical Engineer, Tallassee Power Co., Badin, N. C.

SANTA-MARIA, DOMINGO, Engineer of Direction, de Servicios Electricos, Santo Domingo 1220, Santiago, Chile, So. Amer.

SIEMERS, FREDERIC W., 9610 38th Ave., Corona, N. Y.

SMITH, CLIFTON EDWARD, Electrical Engineer, J. Livingston & Co., 70 E. 45th St., New York, N. Y.

SMITH, GEORGE J., Designer, Binghamton Light, Heat & Power Co., 172 Washington St., Binghamton, N. Y.

SWEET, JAMES W., Operating Engineer, Virginia Public Service Co., Ronceverti, W. Va.

TANTON, FREDERICK WILLIAM, Operator, Power Dept., Newfoundland Power & Paper Co., Deer Lake, Newfoundland; *for mail*, Charlottetown, P. E. I., Can.

TASKER, HOMER G., Engineer, The Pacific Tel. & Tel. Co., 140 New Montgomery St., San Francisco, Calif.

TEVONIAN, HAGOP PUZANT, Designer, Brooklyn Edison Co., Pearl & Johnson Sts., Brooklyn, N. Y.

TUCKERMAN, LUCIEN POMEROY, Research Engineer, De Forest Radio Co., Central Ave. & Franklin St., Jersey City, N. J.; res., Brooklyn, N. Y.

WINTERS, GLENN H., Electrical Draftsman Sargent & Lundy, Inc., 72 W. Adams St., Chicago, Ill.

Total 57.

*Formerly Enrolled Students.

ASSOCIATES REELECTED SEPTEMBER 24, 1926

BROOME, GEORGE WILEY, Electrical Designer, Stevens & Wood, Inc., 120 Broadway, New York, N. Y.

WEISS, HENRY E., Local Manager, Allis-Chalmers Mfg. Co., 915 Kearns Bldg., Salt Lake City, Utah.

ASSOCIATE REINSTATED SEPTEMBER 24, 1926

MARION, FREDERICK R., Communication Engineer, N. Y. N. H. & H. R. R. Co., New Haven, Conn.

MEMBERS ELECTED SEPTEMBER 24, 1926

HUNTINGTON, SCOTT ALLEN, Plant Engineer, The Syracuse Lighting Co., Inc., 421 Warren St., Syracuse, N. Y.

JANSSON, GUSTAV EMANUEL, General Engineer, Condit Electrical Mfg. Co., 1344 Hyde Park Ave., Boston; *for mail*, Wollaston, Mass.

JEANNIN, HARRY WALLACE, Vice-President of Engg., The Jeannin Electric Co., Toledo, Ohio.

JENNENS, WALTER SAMUEL, Electrical Engineer, Ohio Brass Co., Mansfield, Ohio.

LAPIROFF-SCOBLO, M., Professor of Elec. Engg., Government Electro-Technical Institute, Gorohvsakaya 23, U. S. S. R. Moscow, Russia.

WELLER, GEORGE LOUIS, Telephone Engineer, The Chesapeake & Potomac Telephone Co. & Associated Companies, 725, 13th St., N. W., Washington, D. C.

FELLOW ELECTED SEPTEMBER 24, 1926

MELSOM, SYDNEY WILLIAM, Head of Research Dept., Callendars Cable Co., Belvidere, Kent; res., London, Eng.

TRANSFERRED TO GRADE OF FELLOW SEPTEMBER 24, 1926

BOLSER, M. O., Assistant Electrical Engineer, Department of Water & Power, City of Los Angeles, Calif.

CRAFT, EDWARD B., Executive Vice-President, Bell Telephone Laboratories, New York, N. Y.

KELLEY, WILL G., Asst. Engineer of Distribution, Commonwealth Edison Co., Chicago, Ill.

MacCUTCHEON, A. M., Engineering Vice-President, Reliance Electric & Engineering Co., Cleveland, Ohio.
ORSETTICH, ROBERT, Chief Engineer, Wilton Works of General Electric Co., Birmingham, England.
POWELL, ALVIN L., Manager, Engineering Dept., Edison Lamp Works, Harrison, N. J.
SILVER, ARTHUR E., Consulting Electrical Engineer, Electric Bond & Share Co., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER SEPTEMBER 24, 1926

AMBROSE, FREDERIC B., Engineer, Duquesne Light Co., Pittsburgh, Pa.
BENHAM, C. F., Asst. to General Supt., Great Western Power Co., San Francisco, Calif.
BLACKWELL, EDWARD S., Asst. Supt. of Construction, Div. of Construction & Engineering, Stone & Webster, Inc., Pinehurst, Wash.
BOSTWICK, THOMAS J., Chief Electrical Engineer, Aluminum Company of America, Pittsburgh, Pa.
BURGER, EMMETT E., Electrical Engineer, General Electric Co., Schenectady, N. Y.
CHUBBUCK, L. B., Electrical Engineer, Canadian Westinghouse Co., Hamilton, Ont., Can.
COLE, GUERNEY H., Section Engineer, M. & P. Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
CURTIS, EDWARD C., Chief Engineer, Cia Cubana de Electricidad, Inc., Havana, Cuba.
DACE, FRED E., Head, Department of Electricity, Bradley Polytechnic Institute, Peoria, Ill.
DOERSCHUK, HERBERT M., Electrical Supt., Aluminum Co. of America, Niagara Falls, N. Y.
FINNEY, ALFRED C., Consulting Engineer, (Switchboard Practice), General Electric Co., Schenectady, N. Y.
FOGLER, WILLIAM A., Laboratories Supt., Philadelphia Electric Co., Philadelphia, Pa.
GARDNER, STERLING M., President & Chief Engineer, Gardner Electric Mfg. Co., Emeryville, Calif.
GIBBS, JESSE B., Electrical Engineer, Westinghouse Electric & Mfg. Co., Sharon, Pa.
GLANCY, ROBERT C., Chief Engineer, Eastern Bell Telephone Co. of Pennsylvania, Philadelphia, Pa.
GRAY, FRED J., Transmission Engineer, Upstate Territory, New York Telephone Co., Albany, N. Y.
HALPERIN, HERMAN, Engineer, Commonwealth Edison Co., Chicago, Ill.
HENNINGSEN, EARLE S., Electrical Engineer, A. C. Engg. Dept., General Electric Co., Schenectady, N. Y.
HOLLAND, WAYMAN A., Electrical Engineer, Switchboard Dept., General Electric Co., Schenectady, N. Y.
JOHNS, ALBERT N., Consulting Engineer, Los Angeles, Calif.
JOHNSON, CLARENCE N., General Engineer, Westinghouse Electric & Mfg. Co., Philadelphia, Pa.
KARKER, EARL C., Instructor in Electrical Engineering, Mechanics Institute, Rochester, N. Y.
KELMAN, J. N., President & Manager, Kelman Electric & Mfg. Co., Los Angeles, Calif.
KERR, HENRY H., Supt., Electric Operating Dept., Public Service Company of Colorado, Denver, Colo.
KIDDER, JAMES W., Supervising Engineer, New England Tel. & Tel. Co., Boston, Mass.
LUKE, GEORGE E., Research Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
LUTZ, ROBERT A., Electrical Engineer, Utilities Power & Light Corp., Chicago, Ill.
MARR, GEORGE M., Manager, Marine Sales, Charles Cory & Son, Inc., New York, N. Y.
MAYER, J. H., Equipment Engineer, Postal Telegraph Cable Co., New York, N. Y.
McCLAIN, JOHN R., Materials & Process Engineer, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
McNEELY, JOHN K., Research Professor of Electrical Engineering, Iowa State College, Ames, Iowa.
MILLER, GEORGE M., Supt., Electric Distribution & Construction, Louisville Gas & Electric Co., Louisville, Ky.
NIGH, EDSON R., Supt., Light & Power, Puget Sound Power & Light Co., Bremerton, Wash.
NORRIS, FERRIS W., Asst. Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.
PETERS, ALFRED S., Valuation Engineer, Mountain States Tel. & Tel. Co., Denver, Colo.
PRAGST, ERNEST W., Electrical Engineer, General Electric Co., Schenectady, N. Y.
REYNOLDS, WILLIAM H., Foreman of Elec. Maintenance of Erie Works, General Electric Co., Erie, Pa.
RICE, CHESTER W., Research Engineer, General Electric Co., Schenectady, N. Y.
RIGGS, ALBERT C., Supt., Light & Power, Puget Sound Power & Light Co., Bellingham, Wash.
SEIBEL, CHARLES F., Jr., Telephone Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.
SMITH, GLEN H., Engineer, Outside Construction, Department of Lighting, City of Seattle, Wash.
SMITH, J. BRODIE, Vice-President & General Manager, Manchester Traction, Light & Power Co., Manchester, N. H.
SNOW, WILBER C., Industrial Power Salesman, Lighting Department, City of Seattle, Wash.
SPARAGEN, WILLIAM, Secretary, Division of Engineering and Industrial Research, National Research Council, New York, N. Y.
SWOBODA, ADOLPH R., Apparatus Development Engineer, Bell Telephone Laboratories, New York, N. Y.
TREAT, ROBERT, Section Head, Central Station Engg. Dept., General Electric Co., Schenectady, N. Y.
TRUMBULL, ARTHUR J., Assistant Engineer, Distribution Department, Brooklyn Edison Co., Inc., Brooklyn, N. Y.
WAITE, LESLIE O., Engineer, Stone & Webster, Inc., Boston, Mass.
WALLIS, CHARLES R., Sales Engineer, General Electric Co., Seattle, Wash.
WALTHER, JOHN T., Professor of Electrical Engineering, Municipal University of Akron, Akron, Ohio.
WARD, RALPH B., Chief, Electrical Bureau, Newark, N. J.
WATKINS, SAMUEL S., Electrical Engineer, Gibbs & Hill, New York, N. Y.
WIESEMAN, ROBERT W., Special Designing Engineer, A. C. Engg. Dept., General Electric Co., Schenectady, N. Y.
WILSON, HARRY R., Central Station Engineering Dept., General Electric Co., Schenectady, N. Y.
WOOD, EDWIN D., Electrical Operating Engineer, Louisville Gas & Electric Co., Louisville, Ky.
WOODS, GEORGE M., General Engineering, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
WOODSON, J. C., Manager, Industrial Heating Engineering Dept., Westinghouse Electric & Mfg. Co., Mansfield, Ohio.
YERXA, RUSSELL A., Electrical Supt., Dwight P. Robinson & Co., New York, N. Y,

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before October 31, 1926.

Almgren, E. W., Almgren Bros. & Lindberg, Tiger, Colo.
Andree, J. W., (Member), So. California Edison Co., Los Angeles, Calif.
Bailey, G. S., Great Western Power Co., San Francisco, Calif.
Bailey, R. E., (Member), Utah Power & Light Co., Park City, Utah
Banks, W. H., New York Edison Co., New York, N. Y.
Bell, W., Pine Hill Coal Co., Minersville, Pa.
Berg. J. E., Victor X-Ray Corp., Chicago, Ill.
Bernt, A. C., General Electric Co., Bloomfield, N. J.
Burbank, J. D., Niagara Lockport & Ontario Power Co., Buffalo, N. Y.
Chesnut, F. T., Gibbs & Hill Co., New York, N. Y.
Corrin, J. G., Pittsburgh Transformer Co., San Francisco, Calif.
Cowart, J. E., Thomas E. Murray & Co., New York, N. Y.
Dakin, F., General Electric Co., Pittsfield, Mass.
Dart, S. C., Oakland Motor Car Co., Pontiac, Mich.
Dempster, J. J., Canadian Westinghouse Co., Ltd., Hamilton, Ont., Can.
Doxey, F. S., General Electric Co., Schenectady, N. Y.
Eckardt, E. M., N. Y. Rapid Transit Corp., Brooklyn, N. Y.
Ein, S., Illinois Steel Co., South Chicago, Ill.
Ernst, J. P., New York Telephone Co., New York, N. Y.
Green, D. C., (Member), Utah Power & Light Co., Salt Lake City, Utah.
Grondahl, L. O., Union Switch & Signal Co., Swissvale, Pa.
(Applicant for re-election.)
Hale, J. A., (Member), Utah Power & Light Co., Salt Lake City, Utah
Hammond, T. A., General Electric Co., Pittsfield, Mass.
Hawkes, C. J., (Member), The Electric Storage Battery Co., Seattle, Wash.
Hoffmann, H. J., Stone & Webster, Inc., Boston, Mass.
Jones, A. L., Utah Power & Light Co., Salt Lake City, Utah
Keath, H. B., (Member), Wagner Electric Corp., St. Louis, Mo.
Kundert, A., The New York Edison Co., New York, N. Y.
Libecap, R. E., Superior Electric Co., Dallas, Texas
Lindell, K. S. I., Schweitzer & Conrad, Inc., Chicago, Ill.
Lockwood, E. L., Newport News & Hampton Ry., Gas & Electric Co., Hampton, Va.
McCartney, C. E., Southern Cities Power Co., Chattanooga, Tenn.
Niederer, E., Curtis Mfg. Co., St. Louis, Mo.
Norris, W. J., New York Rapid Transit Co., New York, N. Y.
Owens, S., Bureau of Safety, Chicago, Ill.
Parker, J. B., Saskatchewan Government Telephones, Regina, Sask., Can.
Pecha, A. F., Electrical Testing Laboratories, New York, N. Y.
Perlewitz, J. M., Graybar Electric Co., Salt Lake City, Utah
(Applicant for re-election.)
Phillips, A., Electrical Testing Laboratories, New York, N. Y.

Pontius, P. A., Westinghouse Elec. & Mfg. Co., Homewood, Pa.
Prior, F. O., (Member), Midwest Refining Co., Casper, Wyo.
Reinstidt, J. W., Southern Bell Tel. & Tel. Co., Louisville, Ky.
Remscheid, E. J., General Electric Co., Schenectady, N. Y.
Robinson, J. P., Kerite Insulated Wire & Cable Co., San Francisco, Calif.
Rooney, F. H., (Member) Columbia Steel Corp., Provo, Utah
Save, G. A., New York Edison Co., New York, N. Y.
Schoberth, G., New York Edison Co., New York, N. Y.
Scurrah, W., Canadian Marconi Co., Montreal, Que., Can.
Seyler, P. K., Mountain States Tel. & Tel. Co., Salt Lake City, Utah
Sharp. S. M., Minnesota Power & Light Co., Duluth, Minn.
Simpson, J. C., Bell Telephone Co. of Canada, Montreal, Que., Can.
Smith, W. B., Lapp Insulator Co., Los Angeles, Calif.
Steindorf, H. A., Riter Conley Construction Co., St. Louis, Mo.
Szenes, A., New York Edison Co., New York, N. Y.
Vaughan, F. F., (Member), Phoenix Utility Co., Miami, Fla.
Watters, R. A., with Dr. H. B. Spencer (X-Ray Laboratory), Lynchburg, Va.
Weitmann, O., Sloan & Chace, Inc., Newark, N. J.
Werth, J. R., (Fellow), Appalachian Electric Power Co., Lynchburg, Va.
Whittaker, C. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa. (Applicant for re-election.)
Wiack, J. W., Western Electric Co., Inc., New York, N. Y.
Wills, F. P., Adirondack Power & Light Co., Ltd., Schenectady, N. Y.
Yarling, F. C., Louisville Gas & Elec. Co., Louisville, Ky.
Total 62

Foreign

Banwet, D. N., Public Works Dept., Punjab, India
Cutten, W. L., Palmerston North Borough Council, Palmerston North, N. Z.
Hill, W., Oorgaum, Kolar Gold Fields, South India
Hofmann, A. Cl., G. Rohland & Co., Berlin-Charlottenburg, Germany
Kameda, M., Tokyo Electric Light Co., Demki-ka, Tokyo Dento Kabushi Kaisha, Tokyo, Japan
Rendell, E. F., (Member), The Victoria Falls & Transvaal Power Co., Ltd., Cleveland, Transvaal, So. Africa
Setty, K. S., Chengalvaroya Naikers Tech. Institute, Vepery, Madras, India
Uren, T. L., Malvern Electric Power Board, Christchurch, N. Z.
Velasco, A. P., Sorocagana Railway, Sao Paulo, Brazil, So. Amer.
Watkin, H., Nottingham Corp., Nottingham, Eng.
Total 10

STUDENTS ENROLLED

Hayes, R. A. H., McGill University
Huggler, G. Clarence, Pennsylvania State College
Johnson, George Carl, Northeastern University
Leonard, Richard J., Northeastern University
Mueller, Rudolf B., Univ. of Wisconsin
Peters, Jack B., Mass. Inst. of Technology
Total 6

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A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France.
F. W. Willis, Tata Power Companies, Bombay House, Bombay, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
P. H. Powell, Canterbury College, Christchurch, New Zealand.
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(A list of the personnel of Institute committees may be found in the September issue of the Journal.)

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Coordination of Institute Activities, Farley Osgood
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Standards, J. Franklin Meyer
Edison Medal, Gano Dunn
Code of Principles of Professional Conduct, John W. Lieb
Columbia University Scholarship, W. I. Slichter
Award of Institute Prizes, E. B. Meyer
Safety Codes, J. P. Jackson

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Technical Activities, A. G. Pierce

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Instruments and Measurements, A. E. Knowlton
Applications to Iron and Steel Production, A. G. Pierce
Production and Application of Light, Preston S. Millar
Applications to Marine Work, G. A. Pierce
Applications to Mining Work, W. H. Lesser
General Power Applications, A. M. MacCutcheon
Power Generation, H. W. Eales
Power Transmission and Distribution, Philip Torchio
Protective Devices, F. L. Hunt
Research, John B. Whitehead
Transportation,

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(The Institute is represented on the following bodies; the names of the representatives may be found in the September issue of the Journal.)

American Association for the Advancement of Science, Council
American Bureau of Welding
American Committee of Electrolysis
American Engineering Council
American Engineering Standards Committee
American Marine Standards Committee
American Year Book, Advisory Board
Apparatus Makers and Users Committee
Board of Trustees, United Engineering Society
Charles A. Coffin Fellowship and Research Fund Committee
Committee on Elimination of Fatigue, Society of Industrial Engineers
Engineering Foundation Board
John Fritz Medal Board of Award
Joint Committee on Compensation, Charles F. Scott
Joint Committee on Welded Rail Joints
Joint Conference Committee of Four Founder Societies
Library Board, United Engineering Society
National Fire Protection Association, Electrical Committee
National Fire Waste Council
National Museum of Engineering and Industry, Board of Trustees
National Research Council, Engineering Division
National Safety Council, Electrical Committee of Engineering Section
The Newcomen Society
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U. S. National Committee of the International Electrotechnical Commission
U. S. National Committee of the International Illumination Commission
Washington Award, Commission of

LIST OF SECTIONS

Name	Chairman	Secretary
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Baltimore	W.B. Kouwenhoven	R. T. Greer, Madison St. Building, Baltimore, Md.
Boston	Hartley Rowe	W. H. Colburn, 39 Boylston St., Boston, Mass.
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Columbus	A. W. Janowitz	E. A. Williams, 231 N. Fifth St., Columbus, Ohio
Connecticut	A. E. Knowlton	R. G. Warner, Yale University, 10 Hillhouse Ave., New Haven, Conn.
Denver	W. H. Edmunds	R. B. Bonney, Telephone Bldg., P. O. Box 960, Denver, Colo.
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Erie	F. A. Tennant	L. H. Curtis, General Electric Co., Erie, Pa.
Fort Wayne	D. W. Merchant	C. F. Beyer, General Electric Co., Fort Wayne, Ind.
Indianapolis-Lafayette	J. B. Bailey	C. A. Fay, 4206 Cornelius Ave., Indianapolis, Ind.
Ithaca	R. F. Chamberlain	G. F. Bason, Electrical Engineering Dept., Cornell University, Ithaca, N. Y.
Kansas City	R. L. Baldwin	S. M. De Camp, 510 Dwight Bldg., Kansas City, Mo.
Lehigh Valley	W. E. Lloyd, Jr.	G. W. Brooks, Pennsylvania Power & Light Co., 8th & Hamilton Sts., Allentown, Pa.
Los Angeles	R. E. Cunningham	L. C. Williams, H. W. Hellman Bldg., Los Angeles, Calif.
Lynn	D. F. Smalley	Chas Skoglund, River Works, General Electric Co., W.Lynn, Mass.
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Minnesota	S. B. Hood	M. E. Todd, University of Minnesota, Minneapolis, Minn.
Nebraska	C. W. Minard	N. W. Kingsley, 1303 Telephone Bldg., Omaha, Nebr.
New York	E. B. Meyer	O. B. Blackwell, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
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Panama	L. W. Parsons	I. F. McIlhenny, Box 413, Balboa Heights, C. Z.
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Pittsburgh	W. C. Goodwin	D. M. Simons, Standard Underground Cable Co., Cor. 17th & Pike Sts., Pittsburgh, Pa.
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Portland, Ore.	J. C. Henkle	J. E. Yates, Gasco Bldg., Portland, Ore.
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Rochester	Earl C. Karker	Wade H. Reichard, General Ry. Signal Co., Rochester, N. Y.
St. Louis	W. H. Millan	L. N. Van Hook, 3869 Park Ave., St. Louis, Mo.
San Francisco	D. I. Cone	A. G. Jones, 807 Rialto Bldg., San Francisco, Calif.
Saskatchewan	S. R. Parker	W. P. Brattle, Dept of Telephones, Telephone Bldg., Regina, Sask.
Schenectady	R. E. Doherty	R. F. Franklin, Room 301, Bldg. No. 41, General Electric Co., Schenectady, N. Y.
Seattle	C. E. Mong	C. R. Wallis, 609 Colman Bldg., P. O. Box 1858, Seattle, Wash.
Sharon	H. L. Cole	L. E. Hill, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Southern Virginia	W. S. Rodman	J. H. Berry, 1338 Rockbridge Ave., Norfolk, Va.
Spokane	Richard McKay	James B. Fisken, Washington Water Power Co., Lincoln & Trent, Spokane, Wash.
Springfield, Mass.	L. F. Curtis	J. Frank Murray, United Electric Light Co., 251 Wilbraham Ave., Springfield, Mass.
Syracuse	C. E. Dorr	F. E. Verdin, 615 City Bank Bldg., Syracuse, N. Y.
Toledo	A. H. Stebbins	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio
Toronto	M. B. Hastings	F. F. Ambuhl, Toronto Hydro-Electric System, 226 Yonge St., Toronto, Ontario
Urbana	J. T. Tykociner	L. B. Archer, 301 Electrical Engineering Lab., University of Illinois, Urbana, Ill.
Utah	B. C. J. Wheatlake	D. L. Brundige, Utah Power & Light Co., Box 1790, Salt Lake City, Utah
Vancouver	R. L. Hall	C. W. Colvin, B. C. Electric Railway Co., 425 Carrall St., Vancouver, B. C.
Washington, D. C.	C. A. Robinson	D. S. Wegg, Dept. of Commerce, Room 817, Pennsylvania Ave., at 19th St., N. W., Washington, D. C.
Worcester	C. F. Hood	F. B. Crosby, Morgan Construction Co., 15 Belmont St., Worcester, Mass.
Total 51		

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Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
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Alabama, University of, University, Ala	C.E. Rankin	Sewell St. John	
Arizona, University of, Tucson, Ariz	J. W. Cruse		Paul Cloke
Arkansas, University of, Fayetteville, Ark	Carroll Walsh	W. H. Mann	W. B. Stelzner
Armour Institute of Technology, Chicago, Ill	M. T. Goetz	C. W. Schramm	D. P. Moreton
Brooklyn Polytechnic Institute, Brooklyn, N. Y	F. Wanpel	Joseph Heller	Robin Beach
Bucknell University, Lewisburg, Pa	A. Fogelsanger	J. D. Johnson	W. K. Rhodes
California Institute of Technology, Pasadena, Calif	Thomas L. Gottier	Alan E. Capon	R. W. Sorensen
California, University of, Berkeley, Calif	C. F. Dalziel	R. S. Briggs	T. C. McFarland
Carnegie Institute of Technology, Pittsburgh, Pa	J. R. Power	R. O. Perrine	B. C. Dennison
Case School of Applied Science, Cleveland, O	C. A. Baldwin	A. B. Anderson	H. B. Dates
Catholic University of America, Washington, D. C	B. J. Kroeger	J. E. O'Brien	T. J. MacKavanaugh
Cincinnati, University of, Cincinnati, O	F. Sanford	W. C. Osterbrock	W. C. Osterbrock
Clarkson College of Technology, Potsdam, N. Y	W. R. MacGregor	L. G. Carney	A. R. Powers
Clemson Agricultural College, Clemson College, S. C	B. V. Martin	W. H. Sudlow	S. R. Rhodes
Colorado State Agricultural College, Ft. Collins, Colo	C. O. Nelson	D. W. Asay	
Colorado, Univerxity of, Boulder, Colo	A. D. Thomas	J. A. Setter	W. C. DuVall
Cooper Union, New York, N. Y	F. H. Miller	H. T. Wilhelm	Norman L. Towle
Denver, University of, Denver, Colo	Harold Henson	Allea Ohlson	R. E. Nyswander
Drexel Institute, Philadelphia, Pa	H. D. Baker	R. S. Eininger, Jr.	E. O. Lange
Florida, University of, Gainesville, Fla	O. B. Turbyfill	R. Theo. Lundy	J. M. Weil
Georgia School of Technology, Atlanta, Ga	W. M. McGraw	F. L. Kaestle	E. S. Hannaford
Idaho, University of, Moscow, Idaho	J. W. Gartin	S. Blore	J. H. Johnson
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Iowa, University of, Iowa City, Iowa	L. Dimond	A. C. Boeke	A. H. Ford
Kansas State College, Manhattan, Kans	A. M. Young	John Yost	C. E. Reid
Kansas, University of, Lawrence, Kans	W. L. Immer	H. R. Hilkey	G. C. Shaad
Kentucky, University of, Lexington, Ky	J. A. Weingartner	C. E. Albert	
Lafayette College, Easton, Pa	A. H. Gabert	F. G. Keim	Morland King
Lehigh University, S. Bethlehem, Pa	F. G. Kear	J. H. Shuhart	J. L. Beaver
Lewis Institute, Chicago, Ill	O. D. Westerberg	R. G. Raymond	F. A. Rogers
Maine, University of, Orono, Me	S. B. Coleman	H. S. McPhee	W. E. Barrows, Jr.
Marquette University, Milwaukee, Wis	R. M. Franey	E. T. Baldwin	J. F. H. Douglas
Massachusetts Institute of Technology, Cambrdgie, Mass	Stuart John	H. W. Geyer	W. H. Timbie
Michigan State College, East Lansing	Mr. Way	Mr. Phelps	L. S. Foltz
Michigan, University of, Ann Arbor, Mich	M. H. Nelson	H. R. Stevenson	B. F. Bailey
Milwaukee, Engineering School of, Milwaukee, Wis	S. A. Moore	B. J. Chromy	B. A. Bovee
Minnesota, University of, Minneapolis, Minn	C. H. Burmeister	J. H. DuBois	H. Kuhlmann
Missouri, University of, Columbia, Mo	M. P. Weinbach	L. Spraragen	M. P. Weinbach
Missouri School of Mines and Metallurgy, Rolla, Mo	W. J. Maulder	R. P. Baumgartner	I. H. Lovett
Montana State College, Bozeman, Mont	W. E. Pakala	J. A. Thaler	J. A. Thaler
Nebraska, University of, Lincoln, Neb	R. Worrest	C. J. Madsen	F. W. Norris
Nevada, University of, Reno, Nev	George Fairbrother	Cornelius Fort	S. G. Palmer

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Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
New York, College of the City of, New York, N. Y.	Harold Wolf	J. Leipziger	Harry Baum
New York University, New York, N. Y.	H. U. Hefty	Henry Och	J. Loring Arnold
North Carolina State College, Raleigh, N. C.	F. P. Dickens	H. Baum	G. C.. Cox
North Carolina, University of, Chapel Hill	H. L. Coe	C. M. Lear	P. H. Daggett
North Dakota, University of, University	V. L. Cox	O. B. Medalen	D. R. Jenkins
Northeastern University, Boston, Mass.	W. P. Raffone	John L. Clark	W. L. Smith
Notre Dame, University of, Notre Dame, Ind.	C. A. Rogge	J. T. Burton	J. A. Caparo
Ohio Northern University, Ada, Ohio	M. Heft	P. W. Wadsworth	J. W. Gray
Ohio State University, Columbus, O.	Lee P. Doyle	J. S. Hoddy	F. C. Caldwell
Ohio University, Athens, Ohio	N. R. Smith	J. E. Quick	A. A. Atkinson
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Oklahoma, University of, Norman, Okla.	G. B. Brady	J. C. Glaze	F. G. Tappan
Oregon Agricultural College, Corvallis, Ore.	F. D. Crowther	E. F. Reddy	F. O. McMillan
Pennsylvania State College, State College, Pa.	F. F. Wilkins	C. C. Huggler	L. A. Doggett
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Pittsburgh, University of, Pittsburgh, Pa.	S. A. Swetonic	L. M. Brush	H. E. Dyche
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Rensselaer Polytechnic Institute, Troy, N. Y.	F. M. Sebast	K. C. Wilsey	F. M. Sebast
Rhode Island State College, Kingston, R. I.	G. A. Eddy	C. Easterbrooks	Wm. Anderson
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Rutgers University, New Brunswick, N. J.	E. C. Siddons	W. H. Bohlke	F. F. Thompson
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South Dakota, University of, Vermillion, S. D.	L. J. Stverak	R. T. Brackett	B. B. Brackett
Southern California, University of, Los Angeles, Calif.	Karl Raife	E. E. Smith	C. E. Guse
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Stevens Institute of Technology, Hoboken, N. J.	D. B. Wesstrom	Gene Witham	Frank C. Stockwell
Swarthmore College, Swarthmore, Pa.	J. S. Donal, Jr.	R. W. Lafore	Lewis Fussell
Syracuse University, Syracuse, N. Y.	K. N. Cook	R. H. Watkins	C. W. Henderson
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Texas, University of, Austin, Tex.	F. W. Langner	H. W. Zuch	J. A. Correll
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Virginia Polytechnic Institute, Blacksburg, Va.	M. R. Staley	R. M. Hutcheson	Claudius Lee
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Washington and Lee University, Lexington, Va.	D. S. McCorkle	C. M. Wood	R. W. Dickey
West Virginia University, Morgantown, W. Va.	R. W. Beardslee	W. F. Davis	A. H. Forman
Wisconsin, University of, Madison, Wis.	Benj. Teare	N. B. Thayer	C. M. Jansky
Worcester Polytechnic Institute, Worcester, Mass.	D. A. Calder	C. H. Kauke	H. A. Maxfield
Wyoming, University of, Laramie, Wyo.	John Hicks	J. O. Yates	G. H. Sechrist
Yale University, New Haven, Conn.	W. W. Parker	J. W. Hinkley	Charles F. Scott
Total 87			

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Recording Voltmeters.—Catalog 1502, 24 pp. Voltmeter Section, describes a complete line of Bristol's recording voltmeters, together with price list. The Bristol Company, Waterbury, Conn.

Testing of Automobile Lamps.—Bulletin 105, 16 pp. Describes the testing and approval of automobile headlamps and tail lamps, with rules and specifications. Includes a list of approved electric headlighting devices. The Electrical Testing Laboratories, 80th Street & East End Avenue, New York.

New Prices for Century Motors.—The Century Electric Company, St. Louis, Mo., has issued new price lists of its repulsion start, induction, single-phase, and squirrel cage induction polyphase motors, effective September 13, 1926. Stocks are maintained at 29 points in the United States and more than 50 elsewhere.

Alternating Current Instruments.—Bulletin 150, 4 pp. Describes Roller-Smith Type HTA portable ammeters, milli-ammeters, voltmeters, and Type HA a-c. single-phase and d-c. wattmeters. **Direct Current Instruments.**—Bulletin 110, 8 pp. Describes Roller-Smith Type HTD portable ammeters, milli-ammeters, voltmeters, milli-voltmeters and volt-ammeters. The Roller-Smith Company, 12 Park Place, New York.

Insulators and Trolley Equipment.—Catalog 20, 945 pages, includes a complete list of all O-B porcelain insulators, trolley and line materials, rail bonds, car equipment and mining materials.

All of the material pertaining to porcelain insulators and hardware, 472 pages, is also being distributed in a separate binding, known as the Insulator Section. This binding is for the convenience of those interested in high tension material only. The books are indexed and have numerous convenient cross-references. The Ohio Brass Company, Mansfield, Ohio.

Lighting Data.—A series of interesting bulletins on illumination and lamps. Bulletin 108B, 24 pp., describes the lighting of offices and drafting rooms; Bulletin LD-114C, 40 pp., explains the theory and characteristics of Mazda lamps; Bulletin LD-117C, 36 pp., is on the calculation of lighting installations (predetermining the illumination); Bulletin LD-134A, 32 pp., refers to the lighting of the metal working industries; Bulletin LD-141A, 48 pp., covers motor car, garage, and display room lighting. It includes the automobile lighting laws of all of the states. Edison Lamp Works of General Electric Company, Harrison, N. J.

NOTES OF THE INDUSTRY

Ferranti, Limited, Establish Branch in New York.—Announcement has been made by Ferranti, Ltd. of Hollinwood, England, that a branch office has been established at 130 West 42nd Street, New York, and that the name of the American branch will be Ferranti, Incorporated.

New Branch Office for Bristol Company.—The Bristol Company, Waterbury, Conn., manufacturers of recording electrical instruments, has opened a branch sales and service office in the U. S. National Bank Building, Denver, Colo., H. T. Weeks, representative, in charge.

Timken Appoints C. H. Johnson.—The Timken Roller Bearing Company, Canton, Ohio, announces that C. H. Johnson has been appointed engineer of the service department. He will have direct charge of installation of Timken bearings in automotive and industrial applications.

Copperweld Steel Company Appoints Representative.—C. J. Spindler of the Valuation and Rate Department of the Illinois Power and Light Corporation with headquarters in Chicago, has accepted a position as representative of "Copperweld" with the Steel Sales Corporation. Mr. Spindler's territory will consist of Illinois, Wisconsin and Michigan.

Manufacturers' Agency Established at San Francisco.—Thomas A. Fawell has recently organized a manufacturers' sales agency at 40 Sansome Street, San Francisco. He now represents Kohlenite Products, Inc., New York, brushes for electrical machinery, and the Martindale Electric Company, Cleveland, motor maintenance equipment, stones, slotters, etc.

Kuhlman Electric Company Opens Branch at Atlanta.—The Kuhlman Electric Company, Bay City, Michigan, manufacturers of power, distribution and street lighting transformers, has announced the opening of a direct factory branch in Atlanta, Ga., located at 411 Glenn Building, Ernest K. Higginbottom in charge. Mr. Higginbottom has represented the Kuhlman Company throughout the southeast during the past two years.

The Jas. R. Kearney Corporation Adds to Staff.—The Jas. R. Kearney Corporation, St. Louis, Mo., announces that the following men have recently joined the organization: Walter A. Heinrich, as chief engineer; Mr. Heinrich was formerly connected with the W. N. Matthews Corporation as electrical engineer. Elon J. DeRight, special sales engineer; Mr. DeRight, until recently, was superintendent of high line construction of the Kansas City Light and Power Company. James R. Kearney, Jr. as advertising manager and secretary; Mr. Kearney is a recent graduate of the University of Missouri. Hal C. Fiske, as assistant designing engineer; Mr. Fiske was formerly connected with the sales organization of the J. E. Sumpter Company, Minneapolis. J. C. Friedrichs, as engineer; Mr. Friedrichs was formerly with the Western Engineering Company, St. Louis, Mo.

Record Breaking Turbine-Generators Being Built by the G-E Company.—The General Electric Company has announced that it will supply the equipment referred to below:

The Edison Electric Illuminating Company, Boston, is to install a 63,000 kw., single-cylinder turbine-generator. This machine will be the largest single-cylinder turbine in the world.

The Southern California Edison Company is to install two tandem-compound turbines, rated at 94,000 kw. at 90 per cent power factor or 105,000 kw. at unity power factor. These will be the largest tandem-compound turbines ever built.

The State Line Generating Company is to install a 208,000 kw. cross-compound turbine-generator in its new generating station on the shore of Lake Michigan. The ultimate capacity of the station is to be 1,000,000 kv., and the turbine-generator now building is the largest of any type yet projected.

Westinghouse Reorganizes Engineering Department.—Reorganization of the General Engineering Department of the Westinghouse Electric and Manufacturing Company has been announced by H. W. Cope, assistant director of engineering.

The reorganization has necessitated the re-allocation of several engineers, four being elevated to managers of engineering. These are F. C. Hanker, manager of Central Station Engineering; S. B. Cooper, manager of Railway Engineering; G. E. Stoltz, manager of Industrial Engineering and W. E. Thau, manager of Marine Engineering. S. A. Staege, formerly section engineer in charge of the paper mill section, has been appointed industrial engineer giving particular attention to the paper mill industry.

Among the other appointments, also announced by Mr. Cope, are: Central Station Engineering—C. A. Powel, R. D. Evans, and C. A. Butcher; Railway Engineering—H. K. Smith, G. M. Woods, and A. H. Candee; Industrial Engineering—E. M. Bouton, C. W. Drake, C. T. Guildford, C. H. Matthews, O. Needham, J. W. Speer, W. W. Spratt, and E. B. Dawson.

The appointment of N. W. Storer as consulting railway engineer in charge of the group handling of Diesel-electric locomotives and rail cars has also been announced.